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Fish Passage Investigations at the Hiram M. Chittenden Locks, Seattle, WA in 2001

by Peter N. Johnson, MEVATEC Corp.
Frederick A. Goetz, USAE, Seattle District
Charles J. Ebel, USAE, Seattle District
Kyle Bouchard, MEVATEC Corp.
Michael E. Hanks, MEVATEC Corp.
Patricia Pearson, MEVATEC Corp.
Adrienne Fox, Shoreline Community College
Larry R. Lawrence, USAE, ERDC

Prepared for U. S. Army Engineer District, Seattle

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
cubic feet / second (cfs)	0.0283	cubic meters / second

Preface

The report herein was prepared by the Fisheries Engineering Team (FET), Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Engineering Division (EPED), Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center, Waterways Experiment Station (WES) with support from the MEVATEC Corporation, 1525 Perimeter Parkway, Suite 500, Huntsville, AL 35806 and the U.S. Army Engineer, Seattle District Environmental Resources Section. The report was prepared by Messrs. Peter N. Johnson (FET), Frederick A. Goetz (USAE Seattle), Charles J. Ebel (USAE Seattle), Kyle Bouchard (FET), Michael E. Hanks (FET), Ms. Patricia Pearson (FET) and Ms. Adrienne Fox (Shoreline Community College) and was conducted under the general supervision of Dr. Mark Dortch, Chief, WQCMB; Dr. Richard Price, Chief, EPED; and Dr. Edwin Theriot, Chief, EL.

Many people made valuable contributions to this study, especially the personnel at the Hiram M. Chittenden Locks. John Post (Project Manager) and Bill Livermore (Chief of Maintenance) provided generous support and expertise with logistical and troubleshooting issues. Tork Christiansen, Cindy Hawthorne, (welders) and Vinnie Schlosser (Schlosser Machine) fabricated deployment and sampling mounts. Steve Hansen, Jim Kragstaedt, and Dave Murray (mechanics) assisted in the equipment deployment. Doug Houck (King County) lent us a boat and other equipment, and assisted with developing the study design of the current profiler research element. Steve Aubert (King County) lent his expert boat driving abilities. Craig Smith (FET) aided with sampling the flows in front of the flume entrances. Bill Nagy (USAE Portland District, Fisheries Field Unit) and Kenneth Ham (Pacific Northwest National Laboratory) developed the hydroacoustic tracking software. Carl Schilt (FET) reviewed a previous version of this report and his suggestions greatly improved it. John Nestler and L. Toni Toney (WES) provided many helpful suggestions on a previous version of this report.

Funding for this study was provided by Seattle District through two USAE authorities, Section 22 Planning Assistance to the States and Section 1135 Environmental Restoration. These authorities include local contribution through a local sponsor with King County as the primary sponsor under both programs. John Lombard, King County Land and Water Resources, provided the major effort and support in gathering the local partnership. Doug Houck (King County) managed funding for the current profiler work.

At the time of publication of this report, Acting Director and Commander of WES was COL John Morrison, EN.

This report should be cited as follows:

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Introduction

The Lake Washington system is highly productive, producing some of the largest salmon smolts (coho, chinook, and sockeye) for their age of any river basin (Burgner 1991; Weitkamp et al. 1995; Meyers et al. 1998; J. Woodey, UW, unpublished data. However, all of its salmon and steelhead runs have been in serious decline since the mid 1980s. The decline in all Lake Washington anadromous fish runs precipitated resource agency and tribal biologists to investigate conditions at the Hiram M. Chittenden Locks (Locks) to try to identify the potential causes for the declines (WDFW 1996). An outgrowth of agency and tribal investigations was the initiation of two Corps studies, the Lake Washington Ship Canal Section 1135 Smolt Passage Improvement Project (Section 1135 Project) and the Lake Washington General Investigation Study (GI Study).

The Section 1135 Project is considered an adaptive management project based on an ongoing series of experimental actions to improve fish passage for juvenile salmon and steelhead migrating through the project area (WDFW 1996; D. Seiler, WDFW, unpublished data; Goetz et al. 1999; USACE 1999; Johnson et al. 2001a, b). In 2000 and 2001, a series of structural and operational changes were made at the Locks – four smolt passage flumes were installed on the spillway, slow fill of the large lock chamber was continued from 1999, barnacles were removed from the large lock filling conduits, and strobe lights were installed around the large lock culvert intakes. The GI Study is subsequent to the Section 1135 Project and includes monitoring studies to assess the need for additional water for fish passage at the Locks, and habitat assessment to identify potential restoration opportunities throughout the Lake Washington Basin.

Understanding of the anthropogenic causes for the decline in Lake Washington anadromous fish stocks is incomplete. Awareness that the Locks may be either a contributing factor to salmon declines or even a “bottleneck” for juvenile fish passage was gained through an interactive, iterative process between resource agency biologists and Corps staff using long-term indicators of system health and specified measurements of existing project operations and controlled or paired evaluations (WDFW 1996; D. Seiler, WDFW, unpublished data; Goetz et al. 1999; USACE 1999; Johnson et al. 2001a, 2001b). The evaluation of that baseline and adaptive monitoring resulted in the current modifications to the Locks through the Section 1135 Project.

For the Section 1135 Project, we have developed restoration and monitoring objectives with explicit hypotheses (described in USACE 1999) to test each major management measure of the recommended restoration plan. The restoration objectives for the LWSC 1135 project are:

1. Increasing smolt passage over the spillway.
2. Minimizing smolt entry (entrainment) into the large lock filling conduits.
3. Minimizing smolt injury during passage through the large lock conduits.
4. Minimizing injury and mortality to chinook salmon in conformance with ESA listing of Puget Sound chinook.

The overall objective for monitoring is to verify the effectiveness of each restoration measure and selected combinations of measures. Under the Section 1135 Project, only two years of project monitoring are planned. Monitoring objectives are divided into long-term and short-term groups. The long-term objective for the project is to develop necessary information to manage the Locks adaptively, implementing the Section 1135 Project as an experiment in maximizing the survival of migratory smolts. Short-term objectives include measurement of smolt passage through major routes at the Locks – smolt passage flumes, spillway gates, and large lock conduits. By individual or combination of elements, short-term monitoring objectives are:

1. Smolt Passage Flumes: Determine the fish collection efficiency of each flume and combination of flumes. Describe fish collection efficiency in comparison to entrainment of smolts into the large lock filling conduits.
2. Spillway Gate(s): Determine relative fish passage numbers with and without smolt passage flume operation. This item was investigated under the GI Study in 2000 but is included here for completeness in describing monitoring objectives.
3. Large Lock Slow Fill Operation: Determine the greatest reduction in smolt entrainment (into the large lock conduits) at the fastest fill time. Describe smolt entrainment during periods with and without flume operation.
4. Strobe Lights: Determine reduction in smolt entrainment (into the large lock conduits) with control (lights off) and test (lights on) treatment study design during seasonal and diel periods of operation.
5. Combined Slow Fill and Strobe Light Operation: Determine the entrainment rate with strobe lights and slow fill in combination.
6. Large Lock Filling Conduits: Determine the injury rate (reduction or non-reduction) for barnacle removal and slow fill, individually and in combination.

In this report, we present second year monitoring results for objectives 1 and 3. Results for objective 2 are reported in Biosonics (2000). Additional results for objectives 1, 3, and 6 will be contained in a forthcoming report Goetz et al. (in prep). Implementation of strobe lights and monitoring for objectives 4 and 5 are in question: the current strobe light equipment has not proven to be reliable under initial operation. If the strobe light equipment is found to be functional and reliable in 2002, we will evaluate objectives 4 and 5 in that year.

The GI study includes an objective of providing additional improvements in fish passage efficiency at the Locks, primarily through finding additional sources of water (conservation or new supply). Additional research elements related to fish passage improvements reported here include:

1. Measurement and characterization of velocity patterns above the Locks as a function of smolt passage flume and saltwater drain operation at the Locks.
2. Measurement and characterization of velocity patterns at the entrance to flumes at one of the spill gates.

3. Monitoring and characterization of juvenile salmonid behavior at the entrance to one of the smolt passage flumes.
4. Video surveys to document juvenile salmonid use of small lock entranceway and filling culverts.
5. Video surveys to document stranding of juvenile or adult salmonids in the diffuser well.

Methods

Site Location and Description

We conducted all the research reported here at the Hiram M. Chittenden Locks, which is located at the outlet of the Lake Washington Ship Canal in Seattle, WA (Figure 1), and is hereafter referred to as The Locks. The Locks primarily functions as a navigation lock for vessels passing between the freshwater Lake Washington system and the saltwater of Shilshole Bay and Puget Sound. About 80,000 vessels pass through the project each year, approximately 80% of which is pleasure craft. Secondarily, the project serves to control the water level of Lake Washington.

From north to south, the Locks consists of a large lock, small lock, a spillway, and an adult fish ladder (Figure 2). The large lock chamber is 24.4 m wide by 251.5 m long and accommodates vessels with drafts as deep as 9.1 m. The chamber is divided into upper and lower halves by a miter gate in the middle. The small lock chamber is 9.1 m wide by 45.7 m long and accommodates vessels with drafts as deep as 4.9 m. The head differential from upstream to downstream of the lock chambers varies from 1.8 to 7.9 m depending on the tidal elevation and the level of Lake Washington. Tide levels measured just downstream from the Locks in Shilshole Bay fluctuate about 3.7 m over the course of each tidal cycle. The spillway is 71.6 m long with six 9.8 m wide openings, each capable of passing about 2700 cfs at maximum discharge. For a second year of testing, the Corps of Engineers installed four experimental flumes in April, 2001, two each in spillbays 4 and 5 (spillbays are numbered from north to south) to increase juvenile salmon passage at the spillway. Throughout this report, the flumes will be referred to as flumes 4A, 4B, 5C, and 5B, north to south. The two flumes in Bay 4 (flumes 4A and 4B) were 0.6 m and 1.2 m wide, respectively. Flumes 5C and 5B were 0.9 m and 1.2 m wide, respectively. All four flumes pass a total of 400 cfs when completely open at full pool.

The large lock chamber is filled via two 4.9 m wide by 4.3 m tall openings (Figure 3) to deep culverts in walls on either side of the entrance to the lock chambers just upstream of the upper miter gates. The culverts route water north and south, respectively, for about 4.5 m before turning westward (90^{o} angles) and constricting to 2.6-m wide by 4.3-m tall. The culvert continues laterally along the chamber walls before emptying into the chamber through a series of 22 (1.2-m wide by 0.6-m high) filling ports. The chamber is filled by opening three pairs of fixed-wheel vertical lift Stoney gate valves located west of the upper miter gates and east of the middle miter gates. The primary technique used to fill the large lock during the course of the study was the "intermediate" valve opening procedure, which lasts up to about 10 minutes at average tide. The procedure is termed intermediate because the time it takes to completely open the valves are intermediate in duration compared to the slow-continuous and graduated valve opening procedures. At low tide, maximum discharge into each culvert is approximately 2200 cfs and discharges greater than 1800 cfs last up to 3 minutes.

Estimating Fish Entrainment

We used two down-looking 6^{0} split beam Precision Acoustic Systems (PAS) transducers, one at each wall, to monitor fish presence near and entrainment into each culvert entrance (Figure 3). The transducers were deployed 1.2 m from the walls and 12 m above the lock entrance floor, and were aimed straight down along the centerline of

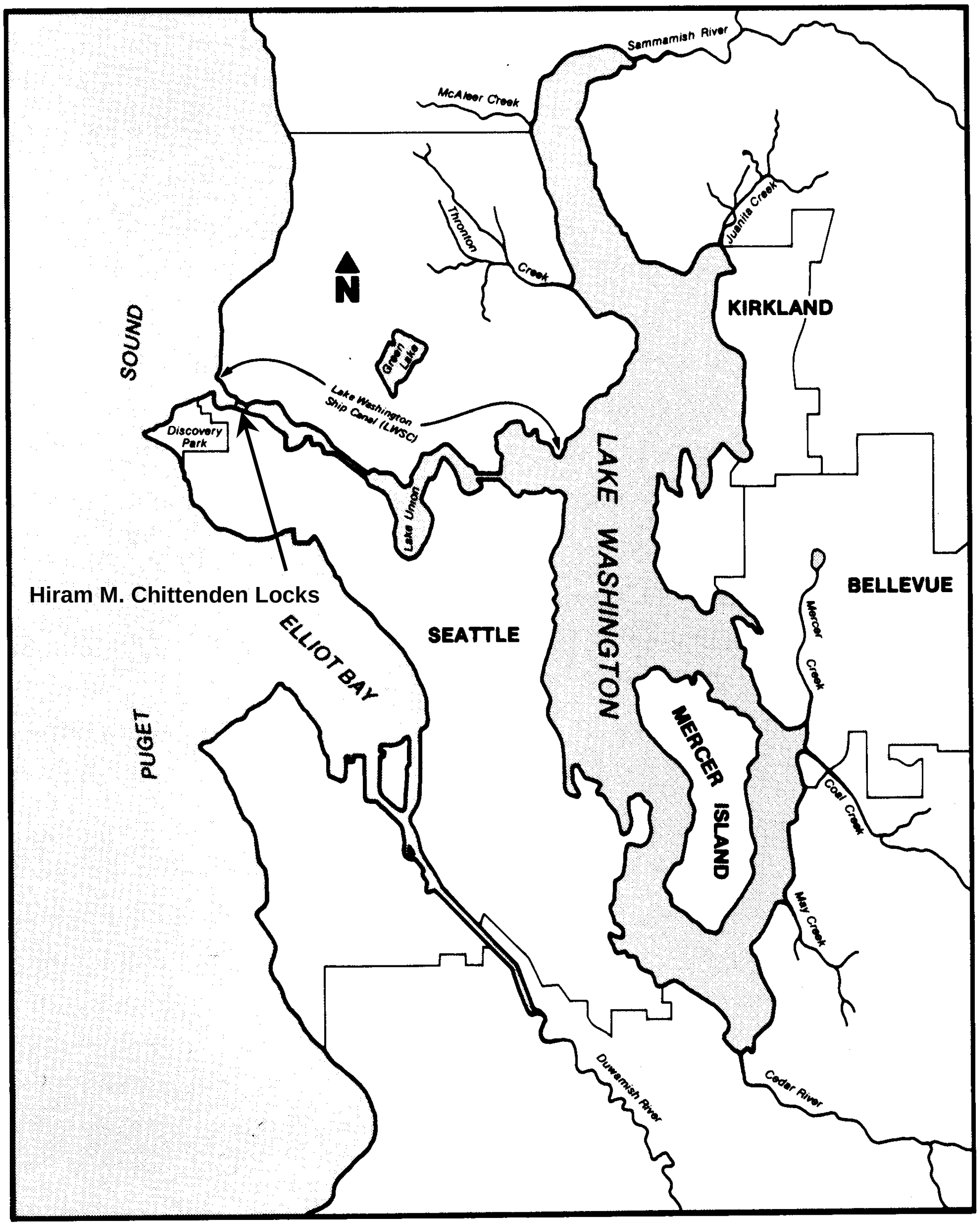

Figure 1. Site map of Lake Washington basin showing the Lake Washington Ship Canal and the location of Hiram M. Chittenden Locks Project.

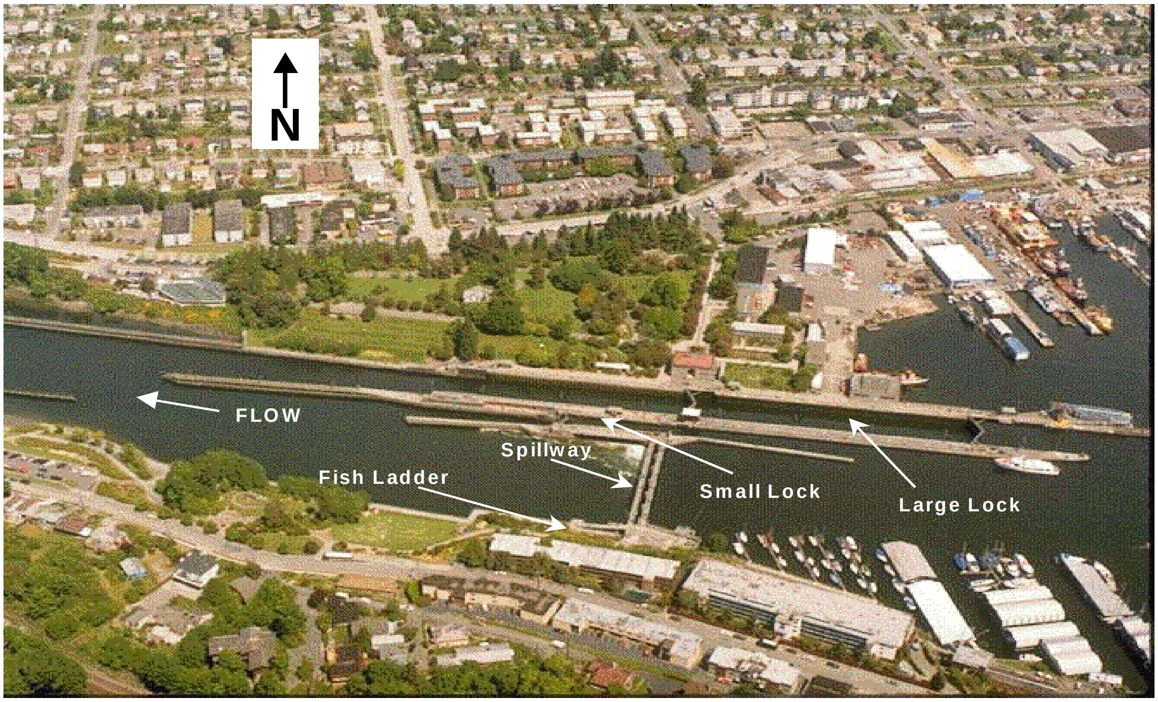

Figure 2. Aerial photograph of the Hiram M. Chittenden Locks Project showing all major structures.

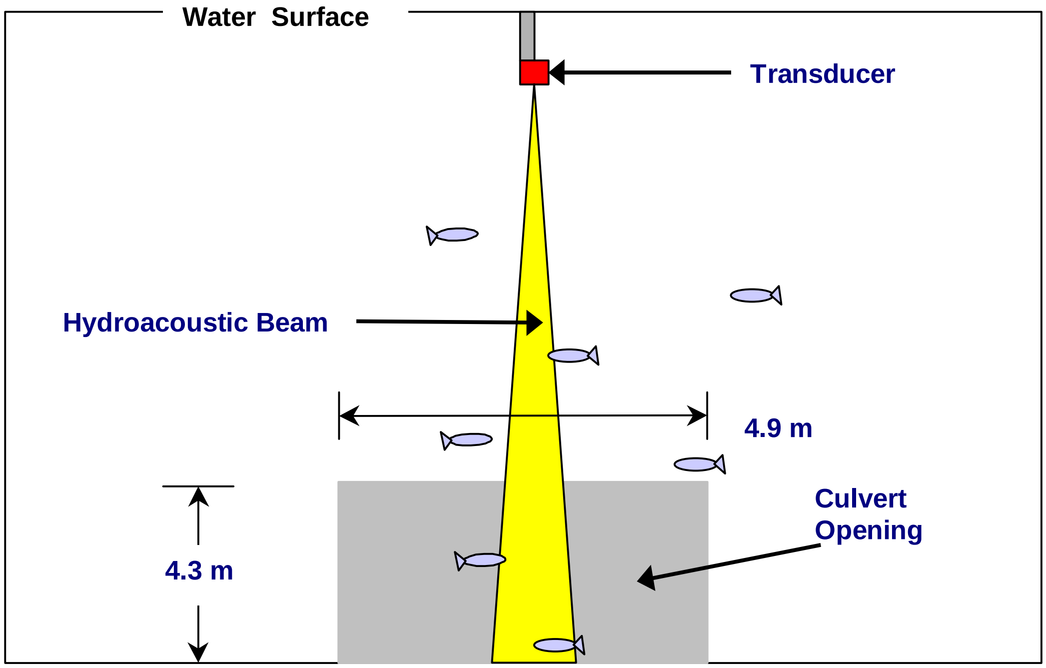

Figure 3. Conceptual diagram of a culvert opening at the Hiram M. Chittenden Locks Project showing the location of the hydroacoustic sampling beam.

the culverts. The width of each sampling beam at the culvert entrance floor was 1.2 m, or about one quarter of the width of the intake. Spring-hinged mounts allowed for the transducers to be folded back against the wall when the miter gates were opened for boat traffic and repositioned for sampling when the miter gates were closed. We operated the transducers using a 420 kHz PAS 103 Multimode Scientific Sounder, PAS 203 Local Surface Multiplexer, and an ACI 200 MHz personal computer loaded with Hydroacoustic Assessment Research Program (HARP) software and equipped with a data acquisition card. We fast-multiplexed the two transducers at 10 pings per second each. We collected hydroacoustic data for at least 23.5 hours per day (approximately 0.5 hour per day lost due to downloading) from 24 April through 7 August.

Detectability Modeling

Detectability of hydroacoustic sampling is the probability of obtaining adequate numbers of echoes from targets of interest passing through a hydroacoustic beam. A number of factors influence detectability, including acoustic size of fish passing through hydroacoustic beams relative to the threshold for data collection (in this case no targets smaller than –56 dB, roughly equivalent to about 4.5 cm in length, were collected), range of targets from transducer, acoustic system configurations, and environmental conditions. The output from detectability models are range-specific effective beam angles (EBA's), a primary factor in estimating spatial expansions of detected fish (see below). We derived EBA's for the down-looking transducers using a Monte Carlo simulation model developed by William T. Nagy, USAE Portland District, Fisheries Field Unit. Model parameters and values used are shown in Table 1. Additionally, equations describing relations between fish trace slope and range (Figure 4) and between two way sound travel and angle off axis (beam directivity) were part of the model (Figure 5).

Acoustic Data Processing

We processed hydroacoustic data from about 30 minutes prior to and through the end of each fill event from 24 April to 7 August (Appendix A). During that time, a total of 796 fill events occurred, of which we sampled 790 (99%). Of these, 154 (19.5%) were full chamber fills and the remaining 636 (80.5%) were upper chamber fills. Full chamber fills entail the use of both the upper and lower chambers. Upper chamber fills were comprised of graduated (n=17), or intermediate (n=619) valve-opening procedures. Full chambers were filled using the intermediate procedure.

Acoustic data processing first entailed translating the output from the HARP acquisition software into a format required for a manual tracking program (Tracker) recently developed by William T. Nagy, USAE, Fisheries Field Unit and revised by Kenneth Ham, Pacific Northwest National Laboratory. We used the Tracker to display the acoustic data in echogram form and save the user-selected fish traces in output files that were later read into Statistical Analysis System (SAS) for post-processing and analysis. The user selects acceptable fish traces by framing the traces with the mouse and clicking on the 'accept' button or by painting echoes. Acceptable traces were defined as traces having greater than 3 echoes and no more than a four-ping gap (four pings without an echo). The tracker has several display schemes for color-coding by echo amplitude. This feature is especially important in noisy environments when low amplitude echoes from bubble clouds can diminish the user's ability to distinguish fish traces from noise. Additionally, the Tracker has a "barrel-view" feature that allows users to view fish traces in the x-y plane, indicating the target's direction of travel.

Table 1. Parameters and values used for hydroacoustic detectability modeling.

Parameter	Value
Nominal Beamwidth in Degrees	6
Beam Tilt in Degrees	0
Near Blanking Range (m)	1
Ping Rate in pings/sec	10
Mean Target Strength (dB)	-45.05
Target Strength Standard Dev. (dB)	3.1
Collection Threshold (dB)	-56
Minimum Echoes for Detection	4
Maximum Ping Gap Allowed	4
Number of Fish for Simulation	500000
Maximum Range (m)	12
Estimated Fish Speed (m/sec)	
Range < 1.5 m	0.14
≥ 1.5 and < 2.5 m	0.14
≥ 2.5 and < 3.5 m	0.18
≥ 3.5 and < 4.5 m	0.2
≥ 4.5 and < 5.5 m	0.19
≥ 5.5 and < 6.5 m	0.22
≥ 6.5 and < 7.5 m	0.23
≥ 7.5 and < 8.5 m	0.27
≥ 8.5 and < 9.5 m	0.29
≥ 9.5 and < 10.5 m	0.28
≥ 10.5	0.26

All tracked fish were spatially expanded based upon Equation 1 below.

$$\text{Expanded Fish} = \text{CW} / (\text{MID\_R} \times \text{TAN}(\text{EBA}/2) \times 2), \qquad (1)$$

where CW is culvert width in m, MID_R is the mid-point range of a trace in m, TAN is the tangent, and EBA is effective beam angle in degrees. Effective beam angle depends upon the detectability of fish of different sizes in the acoustic beam and is a function of nominal beam width and ping rate (pings / sec) as well as fish size, aspect, trajectory, velocity, and range.

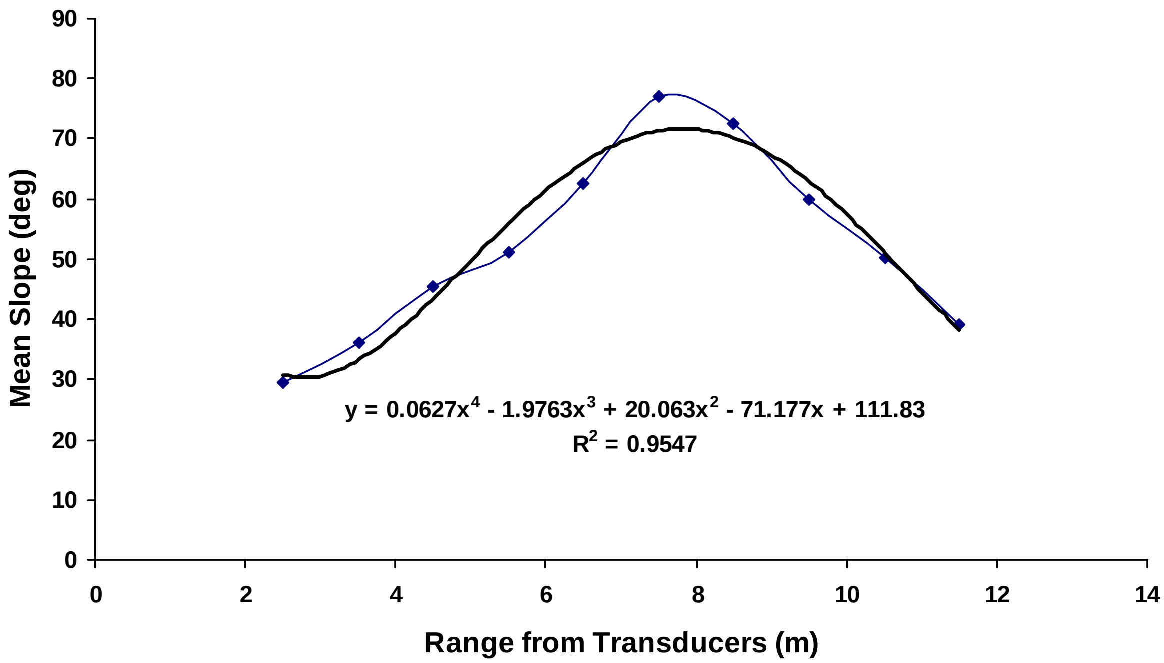

Figure 4. Relation of mean slope of fish traces with range from transducer. The 4th order polynomial equation describing the bold trend line fitted to the data was used in the detectability model.

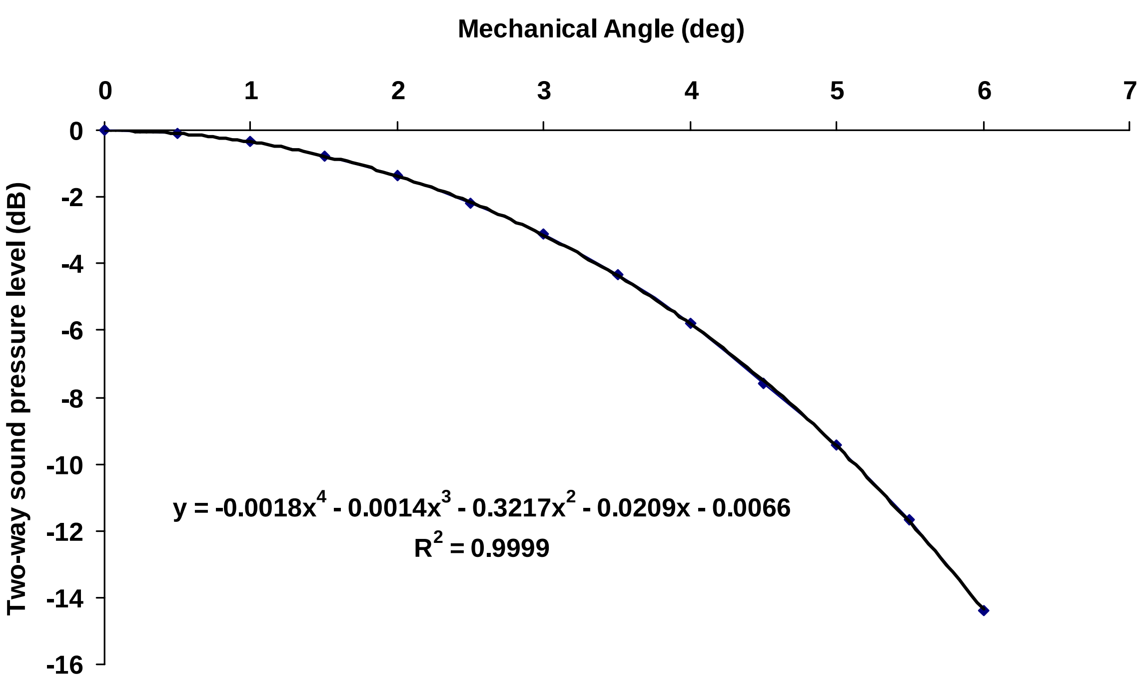

Figure 5. Relation of two-way sound pressure attenuation to mechanical angle for the transducers used to sample fish entrainment through the lock filling culverts. The 4th order polynomial equation describing the bold trend line fitted to the data was used in the detectability model.

Data reported over a diel cycle are standardized based on the number of minutes sampled for each hour of the day over the course of the study. The standardized counts were then expanded to the whole hour. Fish were defined as entrained into the culvert based on their direction of travel (on the azimuth plane) through the beam (Figure 6) for fish distributed from 1 m above the culvert to the floor. With the exception of the target strength distribution analysis, all hydroacoustic data reported herein describe only fish with average target strengths less than –37.5 dB. According to Love's (1977) equation, a fish with average target strength of –37.5 dB sampled at dorsal aspect would equate to a length of 25.5 cm, which is approximately the size of the largest juvenile salmonid likely to be encountered at the Locks.

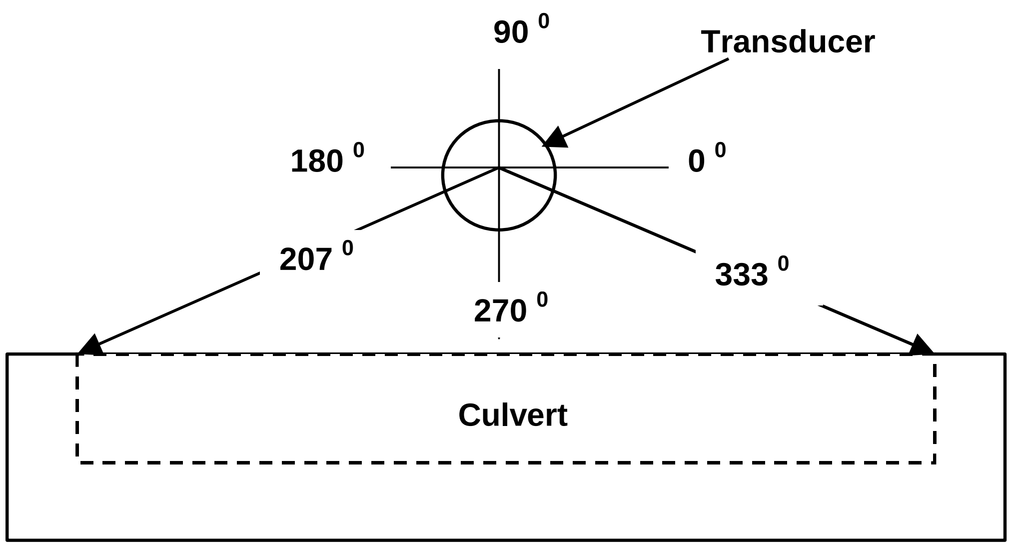

Figure 6. Conceptual diagram in plan view showing the horizontal angle of bearing (azimuth) for fish traces passing through the hydroacoustic beams. Fish traces with midranges from 1 m above the culvert entrance to the floor and with azimuth values between 207 and 333 degrees during fill events were considered to represent entrained fish.

Determination of Fill Event Start Times

We initially obtained start times of each fill event from the daily log of fill events provided to us by the lockmasters, but it was clear from the hydroacoustic data that the start times from the lock logs did not match with the times in the data set. On several occasions, lock log start times were recorded when the miter gates were open. We could tell when gates were opened because horizontal lines appeared across the echograms when the miter gate ribs entered the ensonified sampling volume. This problem was likely the result of using different time indicators (wristwatches, wall clocks, etc.) to reference fill start times among the different shifts of lockmasters.

To obtain more accurate estimates of start times, we used USAE Seattle District water-level data collected from sensors deployed inside the upper and lower lock chambers to determine fill duration as a function of head differential for the various valve-opening procedures used. We calculated regression equations for predicting fill duration given the head differential and then recalculated the equation describing the relationship based only on data points reflecting lower head-per-given duration (Figure 7). Fill event start times were then calculated by subtracting the predicted fill duration from end times based on the miter gate "signature" observed in the echograms. Using this equation prevented us from underestimating fill durations and consequently removing fish that were entrained during the fill startup from the entrained fish estimates.

Estimating Smolt Passage Over Experimental Flumes

The visual count sampling design at the spillway flumes (Figure 8) consisted of positioning observers on the spillway walkway deck overlooking the individual flume outfalls. Each flume was viewed for at least three 5-minute count periods per hour. After a 5-minute count period, the observer moved to a different flume to begin the next 5-minute count period. Initial flume counting position for each hourly sample was randomly chosen. The number of hours counted per day depended upon the availability of our counting staff. Whenever possible, we attempted to visually estimate flume passage for all daylight hours. Counts were generally performed between 0800 and 1700 hours. Five-minute count estimates were recorded into field notebooks and later entered into a spreadsheet. Sub-sampled counts were expanded to full hour estimates and expanded to the day based on the number of daylight hours each flume was operational. Visual counts were obtained from 18 April through 5 August, when the last flume was shut off to conserve water. Table 2 lists the visual count sampling effort by flume and number of hours sampled per day.

Estimating Flume Volume Discharge

We estimated the discharge volume through each flume on a daily basis based on regression of flume volume from lake elevation data and the number of hours each flume was operated per day. The regression equations were calculated based on known volumes of discharge at given lake elevations (data points furnished by Amy Reese, Seattle District Corps, Water Management Group) and were as follows: for Flume 4A (14.54x – 269.89); Flume 5C (24.768x – 459.6); and Flumes 4B and 5B (39.309x – 734.49).

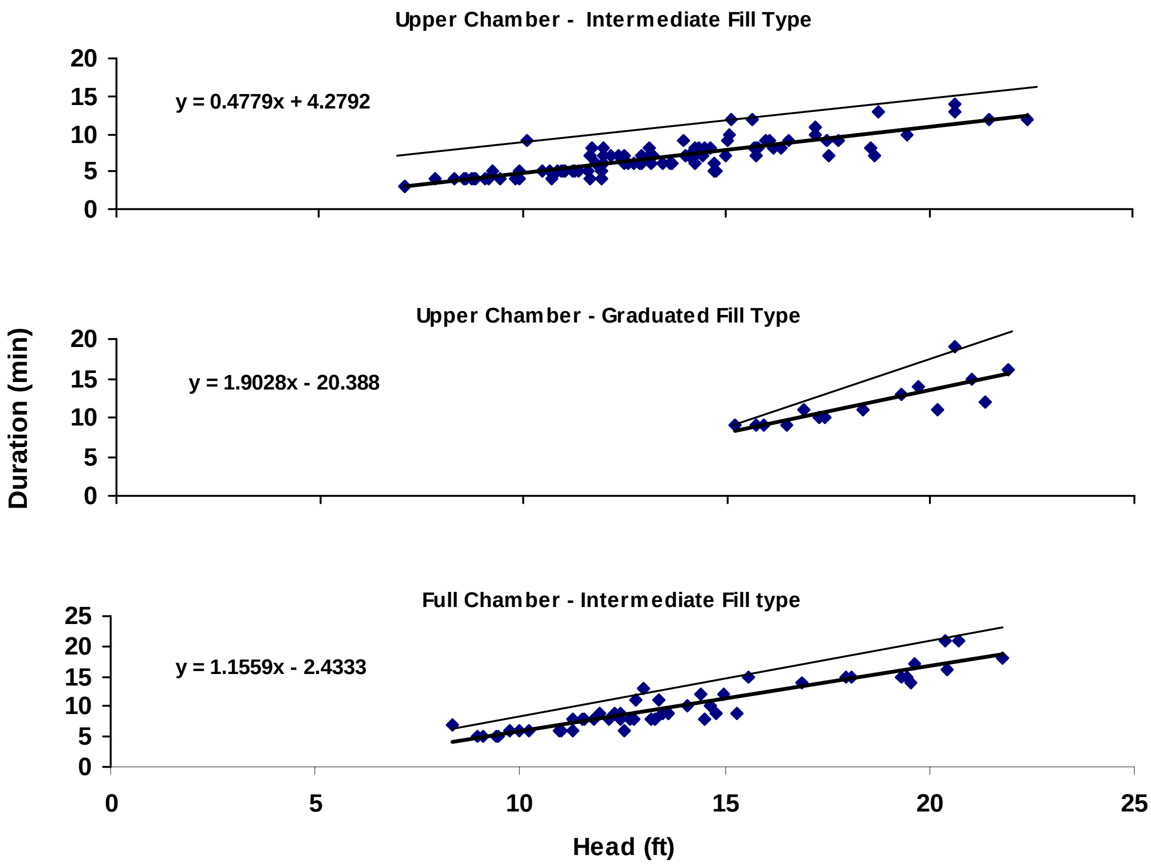

Figure 7. Scatter plots showing the relationship between head differential and fill event duration for all combinations of chamber (full and upper) and valve opening procedures used (intermediate, graduated). The bold trend lines were fitted to all plotted points. The regression equations of the lighter trend lines were used to predict fill durations for all sampled events to be certain that durations were not underestimated.

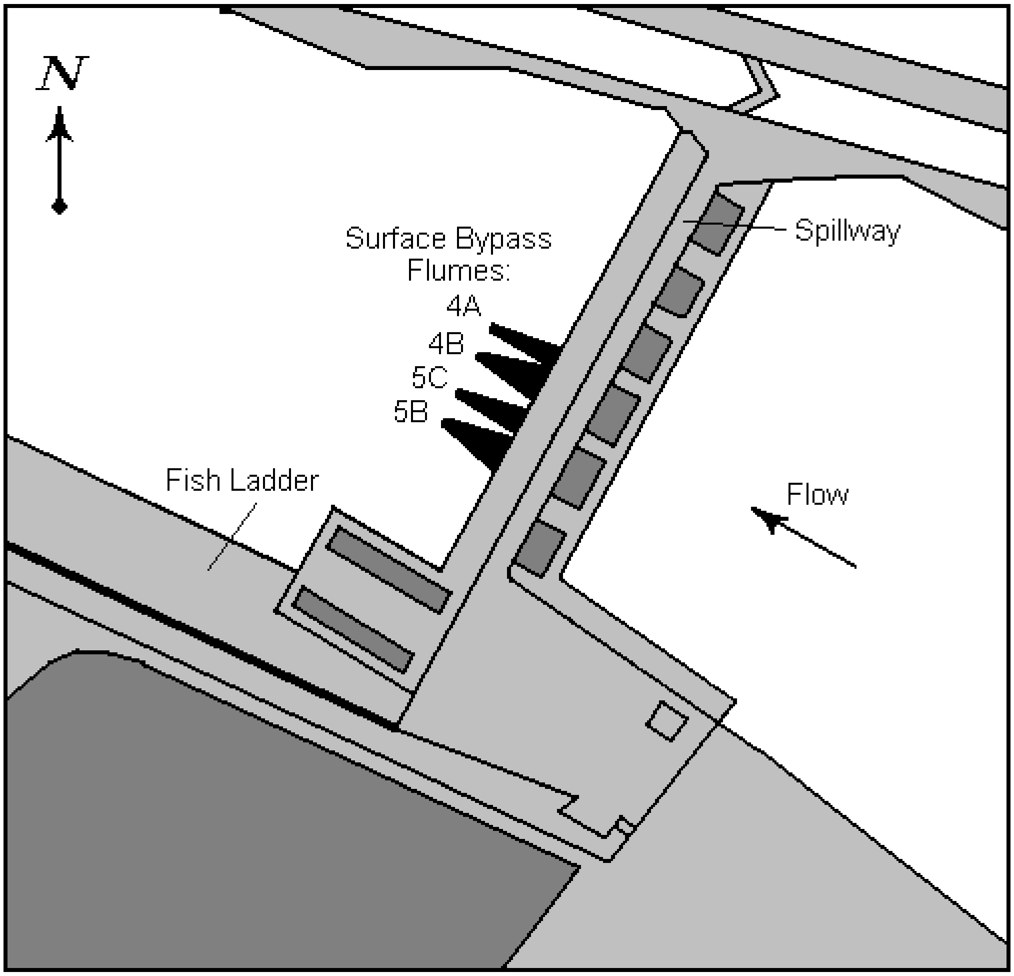

Figure 8. Plan view of the spillway showing the location of the experimental flumes.

Monitoring Smolt Presence in the Entranceway to the Small Lock

The use of the small locks as an outmigration passage route for juvenile salmonids is presently unknown since there have been no efforts to date to monitor entrainment through the small lock filling culverts during fill events. In order to assess the likelihood that the small lock is a potential entrainment hazard, we conducted a number of surveys with a mobile underwater camera system to document the presence or absence of smolts in the entranceway to the small lock and at the filling culverts. The camera system we used consisted of a Fisheye Inc., monochrome Sport Camera, rechargeable 12 V battery pack, Sony GV-D900 Video Walkman, and I-O Display Systems virtual reality glasses. The camera was mounted to 3.8 cm diameter PVC pipe and either deployed from a boat or from the walkway and upper gates along the small lock entranceway. All surveys were recorded on 60 min Mini DV cassettes tapes for later review. Sampling locations and techniques are described below by date:

<u>24 May (0800-1000)</u>– We lowered the camera to just above the floor of the entrance and started the survey at the east end of the wall and slowly moved downstream to the gate,

Table 2. Number of visually-counted sub-sampled hours per flume per day at the Hiram M. Chittenden Locks in 2001.

Date	Flume 4A	Flume 4B	Flume 5C	Flume 5B	Date	Flume 4A	Flume 4B	Flume 5C	Flume 5B
18-Apr	9	9	7	7	12-Jun	8	8	7	7
19-Apr	0	0	0	0	13-Jun	8	8	8	8
20-Apr	0	0	0	0	14-Jun	8	8	8	8
21-Apr	10	10	10	10	15-Jun	0	0	0	0
22-Apr	8	8	8	8	16-Jun	8	8	8	8
23-Apr	10	10	10	10	17-Jun	0	0	0	0
24-Apr	10	10	10	10	18-Jun	0	0	0	0
25-Apr	8	8	8	8	19-Jun	0	0	8	8
26-Apr	10	10	10	10	20-Jun	0	0	8	8
27-Apr	6	5	6	6	21-Jun	0	0	8	8
28-Apr	0	0	0	0	22-Jun	2	2	9	9
29-Apr	10	0	10	10	23-Jun	0	0	0	0
30-Apr	9	0	9	9	24-Jun	0	0	10	10
1-May	9	0	9	9	25-Jun	0	0	10	10
2-May	7	6	9	9	26-Jun	0	0	9	9
3-May	8	6	8	4	27-Jun	0	5	7	7
4-May	10	10	10	0	28-Jun	0	7	9	9
5-May	8	8	8	8	29-Jun	0	10	10	10
6-May	10	10	10	10	30-Jun	0	8	8	8
7-May	6	6	6	5	1-Jul	0	10	10	10
8-May	8	8	8	8	2-Jul	0	0	4	9
9-May	9	9	9	9	3-Jul	0	0	10	10
10-May	7	7	7	7	4-Jul	0	0	0	0
11-May	8	0	8	8	5-Jul	0	0	10	10
12-May	10	0	10	10	6-Jul	0	0	10	10
13-May	0	0	0	0	7-Jul	0	0	8	8
14-May	8	2	7	7	8-Jul	0	0	10	10
15-May	8	8	8	8	9-Jul	0	0	10	10
16-May	8	8	8	8	10-Jul	0	0	10	10
17-May	4	4	4	4	11-Jul	0	0	8	8
18-May	6	6	6	6	12-Jul	0	0	9	9
19-May	8	8	8	8	13-Jul	0	0	10	10
20-May	0	0	0	0	14-Jul	0	0	8	8
21-May	8	0	8	8	15-Jul	0	0	8	8
22-May	8	0	8	8	16-Jul	0	0	3	5
23-May	1	0	1	6	17-Jul	0	0	0	8
24-May	8	0	8	8	18-Jul	0	0	0	8
25-May	0	0	0	0	19-Jul	0	0	0	8
26-May	0	0	0	0	20-Jul	0	0	0	8
27-May	0	0	0	0	21-Jul	0	0	0	0
28-May	0	0	0	0	22-Jul	0	0	0	10
29-May	0	0	0	0	23-Jul	0	0	0	10
30-May	8	0	8	8	24-Jul	0	0	0	10
31-May	8	0	8	8	25-Jul	0	0	0	8
1-Jun	5	0	5	5	26-Jul	0	0	0	6
2-Jun	0	0	0	0	27-Jul	0	0	0	10
3-Jun	0	0	0	0	28-Jul	0	0	0	7
4-Jun	0	0	0	0	29-Jul	0	0	0	10
5-Jun	4	0	4	8	30-Jul	0	0	0	10
6-Jun	0	0	0	7	31-Jul	0	0	0	10
7-Jun	0	0	1	8	1-Aug	0	0	0	8
8-Jun	0	0	0	0	2-Aug	0	0	0	8
9-Jun	0	0	8	0	3-Aug	0	0	0	10
10-Jun	0	0	0	0	4-Aug	0	0	0	8
11-Jun	0	0	0	0	5-Aug	0	0	0	10

then along the gate before heading back upstream to the end of the south wall. We continuously panned the camera to sample as much area as possible. The camera panning procedure was repeated in all subsequent surveys.

20 June (1100-1200, 1300-1640) – We lowered the camera to 2.4 m below the surface and slowly moved from the east end of the north wall downstream to along the gate and back upstream to the end of the south wall. We then positioned the camera between 5 and 6 m below the surface at the north culvert during a fill and at the same depth at the south culvert during a fill.

22 June (0515-0600) – We positioned the camera about 3 m below the surface at the north culvert during a fill and at the same depth at the south culvert during a fill.

25 June (0630-0730) – We positioned the camera 6 m below the surface in and around the south culvert prior to and during a fill and at the same depth in and around the north culvert prior to a fill.

28 June (1130-1230) – We positioned the camera between 3 and 4.5 m below the surface at the south culvert during a fill. We then positioned the camera 3 m below the surface and slowly moved upstream from the south wall gate to the end of the pier. Lastly, we positioned the camera 3 m below the surface and slowly moved upstream from the north wall gate to the end of the pier.

Characterizing Smolt Behavior at the Entrance to Flume 5B

In order to assess and characterize juvenile salmonid behavior at the entrance to a spillway flume, we deployed a video camera from a pole mounted to the south side of the entrance slide gate of Spillway Bay 5, Flume 5B (Figure 9). The video system consisted of a Sony SSC-M350 monochrome camera fitted with a 105 degree wide-angle lens placed inside a Fuhrman Diversified, Inc. underwater housing, a Sony YS-W250 camera adaptor, a Sanyo SRT-6000 real time video recorder, and a Panasonic TR-990-C 23 cm monochrome video monitor. The camera was positioned at an elevation of 5.46 m (18.9 ft, about 3 ft underwater) and aimed across the flume entrance horizontally in a northward direction. The camera lens was approximately 10 cm north of the south edge and immediately upstream of the 1.83 x 1.26 m flume entrance. Flume passage events were videotaped using Sony T-160 VHS tapes. Effort was made to capture at least eight hours of video data each day, typically starting data collection in the mid-morning. Table 3 lists by date and time all the video data recorded at the entrance to Flume 5B.

The specific objectives of this study element were to assess flume entrance behavior of smolts in terms of fish orientation, approximate group size, proportion of groups visible in the video that enter the flume, and any other observed behaviors. Typically, video data were processed by sub-sampling 25% of each full hour of videotape. For each full hour, three 5-min periods were randomly selected for review. However, a small proportion of the data was processed based on VCR tape counter time instead of recorded time. Reviewers observed the five min periods and noted relative sizes of fish groups, orientations of individual fish (head or tail first, lateral swimming, etc.), proportion of fish groups that entered the flume, direction of travel of fish that did not appear to enter the flume, any predator-prey interactions, and video quality in terms of water clarity, angle of the sun, and algal growth on the lens.

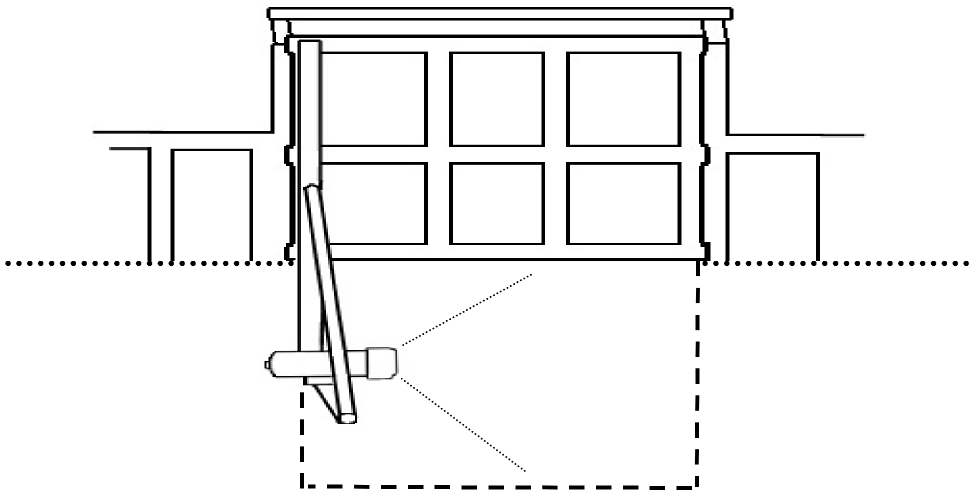

Figure 9. Conceptual drawing showing the location of the underwater video camera used to collect fish behavior data at the entrance to Flume 5B. Dashed line indicates underwater portion of flume entrance. Elevated structure is the slide gate.

Flume Entrance Velocity Sampling

On 8, 9 May we measured the velocity field directly in front of the entrances to flumes 5B and 5C using a Sontek 5 MHz Ocean Probe acoustic Doppler velocimeter (ADV) and a Sontek ADVField processor operated with a Dell Inspiron 7500 laptop computer. The ADV transmits with a single acoustic transmitter located in the center of the probe, and receives on three acoustic receivers that flair out from the bottom of the probe. The ADV sample volume size is 2.0 cm^3 located 18 cm from the transmitter (Figure 10). The ADV uses the physical phenomenon known as the Doppler effect to measure water velocity. The transmitter emits a short pulse of known frequency into the water along the axis of its beam. As the pulse passes through the sampling volume, the acoustic energy is reflected in all directions by particulate matter (sediment, bubbles, small organisms, etc.) and a portion of the acoustic energy is reflected back to the receivers at different frequencies, depending on the change in range from reflector to receiver. This difference in frequencies is known as the Doppler shift and is proportional to the velocity of the particles along the bistatic axis of the receiver and transmitter. The receivers are aligned to intersect with the transmit beam pattern at the common sampling volume. The velocities measured by each receiver are referred to as the bistatic velocities, which are converted to XYZ (Cartesian) velocities using the probe deployment geometry. The XYZ velocities describe the 3-dimensional velocity field relative to the orientation of the probe.

Table 3. List of recorded video data at the entrance to Flume 5B by date and hour.

Date	Start Hour	End Hour	Date	Start Hour	End Hour
18-May	9	15	5-Jul	10	17
19-May	10	16	6-Jul	10	17
20-May	11	17	7-Jul	12	19
21-May	10	17	9-Jul	11	18
22-May	9	16	10-Jul	12	18
25-May	9	16	11-Jul	11	17
27-May	10	17	12-Jul	10	17
28-May	11	17	13-Jul	6	13
29-May	9	6	14-Jul	11	17
30-May	9	16	15-Jul	11	18
31-May	9	16	16-Jul	10	17
2-Jun	11	18	18-Jul	10	17
3-Jun	13	17	19-Jul	9	16
4-Jun	9	17	20-Jul	10	17
5-Jun	8	15	22-Jul	9	15
12-Jun	9	16	23-Jul	11	17
13-Jun	10	17	24-Jul	12	17
14-Jun	10	17	25-Jul	11	17
15-Jun	10	17	26-Jul	11	18
19-Jun	10	17	27-Jul	11	17
4-Jul	10	17	28-Jul	10	17

We used a 1.83 x 3.45 m modified metal cattle gate as a grid to position the ADV at known sampling stations relative to the flume entrances at Spillway Bay 5 (Figure 11). The grid was comprised of 20.32 cm square sections (9 x 17 squares) and positioned over the flow field using ropes tied to the upstream handrails on the upper spillway walkway and C-clamps securing the downstream edge of the grid to the entrance slide gates. The grid was initially positioned such that the southwest corner of the grid was 1.22 m south of the south edge of the entrance to Flume 5B. Once all measurements were made at the first grid position, the grid was moved so the south edge of the grid was located on the north edge of the previously sampled area. Grid repositioning was repeated until we had sampled to a line 1.22 m north of the north edge of the entrance to Flume 5C. The entire sampled area measured 6.1 x 3.45 m.

We attached the ADV to a 3.1 m long aluminum pole and marked the pole in increments of 20.3 cm (Figure 12), which composed the vertical (depth strata) sampling stations. At each grid position sampled, we attempted to collect velocity data at 12 depth strata. The grid was positioned vertically such that the ADV probe in the uppermost vertical sampling position was 2 cm below the water surface resulting in the location of the shallowest sampling volume at 20 cm below the water surface. The ADV

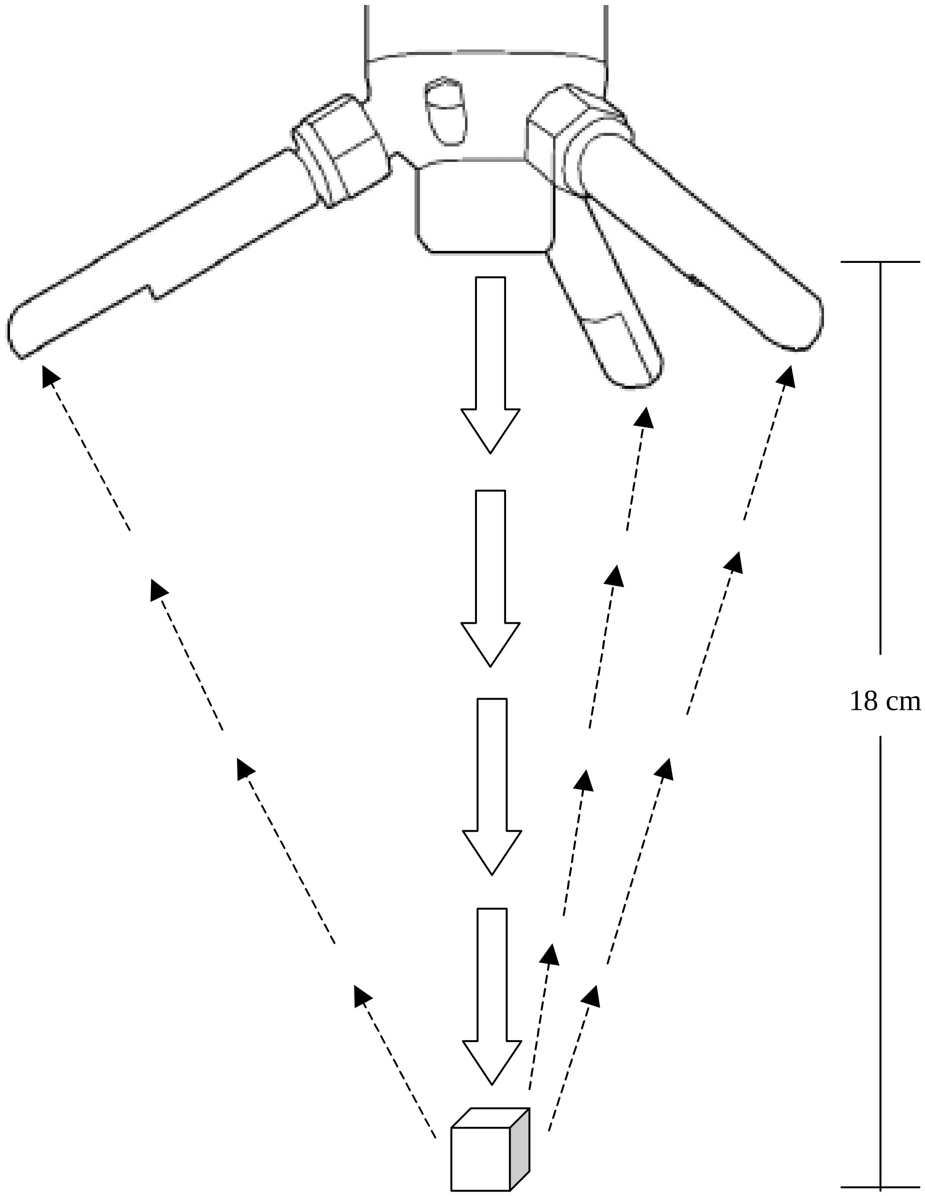

Figure 10. Conceptual drawing of the Sontek ADV Ocean Probe showing the location of the sampling volume relative to the transducers. The transmitter is located at the bottom of the probe between the three legs. The receiving transducers are located near the terminal ends of the legs. The large arrows indicate the direction of the transmitted sound and the small arrows indicate the directions of the reflected sound. The sample volume is approximately 2.0 cm^3.

probe was positioned so that the X-axis was positive into the flume, the Y-axis positive to the north direction, and the Z-axis positive up into the probe toward the water surface. We sampled in every other square grid section, and in each sampled section, the pole and probe were positioned in the southwest corner. We sampled at a rate of 25 Hz, and collected data at each station for 5 seconds.

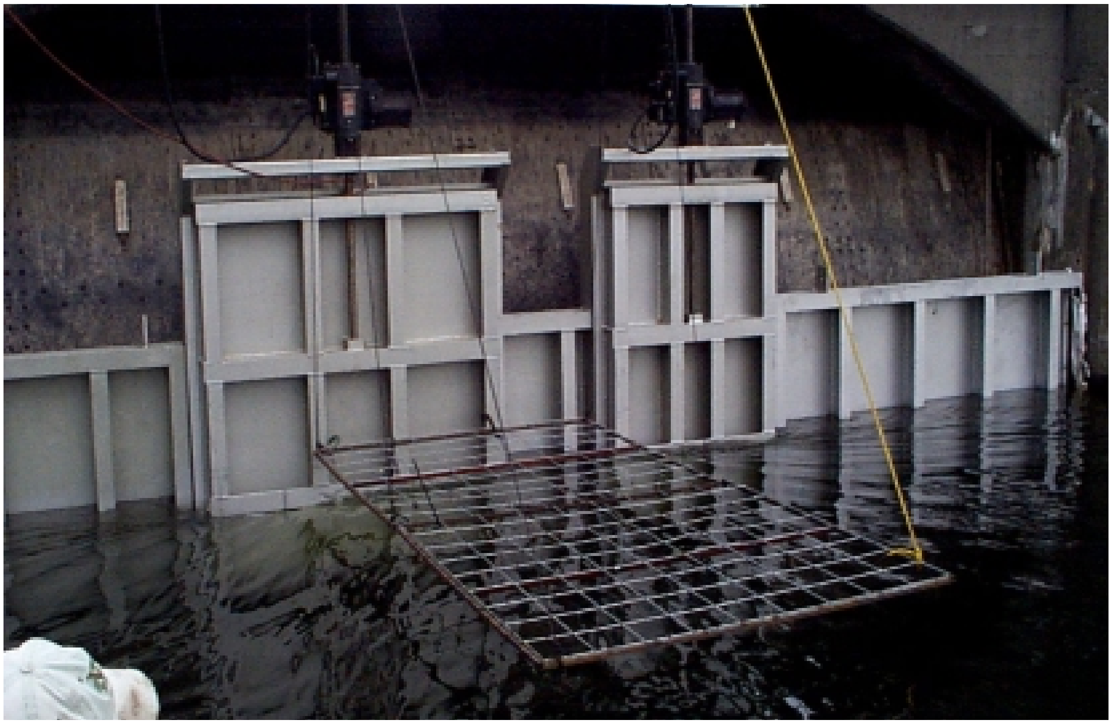

Figure 11. Photograph showing the grid used to position the ADV for sampling the flow field at the entrance to Flumes 5B (on left) and 5C. The flumes are open and the slider gates are shown in the raised position.

The ADV-collected data were filtered by removing data points if the signal-to-noise ratio was less than 15 or the correlation between data within a data point was less than 70% (manufacturer recommended filtering criteria). The signal strength is a measure of the intensity of the reflected acoustic signal, and if the water is too clear the return signal may not be stronger than the ambient noise level of the electronics. The correlation coefficient reflects data quality in terms of the Doppler velocity calculations. The higher the correlation, the more reliable and less noisy are the velocity measurements. Data between sampled points were interpolated using TecPlot software.

During normal operation of the spillway flumes, a V-shaped log boom is placed in the spillway forebay upstream of the flume entrances to prevent trash and large woody debris from clogging the flumes (Figure 13). We removed the log boom in order to deploy the grid and conduct our sampling. After completion of the ADV sampling with the log boom removed, we replaced the log boom and collected additional data with it in place where possible. All sampling conducted with the log boom in place was done from outside the log boom so as to not confound any effects the log boom has on the flow fields.

Figure 12. Photograph showing velocity sampling using a pole-mounted ADV at the entrance to Flume 5B. The demarcations shown on the pole represent vertical strata sampling stations.

The objectives of this research element were to describe and characterize the three-dimensional velocity fields near the entrances to spillway flumes and to discuss the results relative to fish behavior observed with a video camera at the entrance to Flume 5B. Additionally, we wanted to determine the influence the log boom located upstream of spillway bays 4 and 5 had on the flow field at the flume entrances.

Figure 13. Photograph showing the V-shaped log boom upstream from the entrances to the flumes in Spillway Bays 4 and 5. Note the location of the grid just inside the left leg of the log boom (indicated by arrow).

Current Profiler Sampling

To investigate the temporal influence of variable flume operation on flow conditions upstream of the spillway, we conducted a series of transect surveys using a boat-mounted acoustic Doppler current profiler (ADCP). We used an RD Instruments 1200 kHz ADCP with 20^{o} beams operated with a Pentium class laptop computer. Like the ADV, the ADCP uses the Doppler effect to measure current velocity by transmitting sound at a fixed frequency and listening to (receiving) echoes returning from sound scatterers such as sediment or small organisms. However, as the ADV measures velocity at a discreet sampling volume, the ADCP samples a conic volume with predetermined depth bins. The ADCP measures average velocity over the range of the individual depth bins.

We also collected location data with a Global Positioning System (GPS) concurrently with the acquisition of the current velocity data to ensure accurate positioning relative to physical features at the Locks. We surveyed a total of eight north-south transects from just above the spillway log boom upstream to the inflection point on the large lock north wall (Figure 14) in May and June of 2001. We maintained a boat speed of 2 to 3 knots during the course of each transect. The operational conditions during which we collected velocity profile data were:

1) baseline (all outfalls closed except for 4.53 cms (160 cfs) feeding the fish ladder);

2) baseline plus saltwater return of 3.96 cms (140 cfs) for a total of 8.49 cms (300 cfs);

3) baseline plus Flume 5B of 3.68 cms (130 cfs) for a total of 8.21 cms (290 cfs);

4) baseline plus Flume 5B plus saltwater return for a total of 12.17 cms (430 cfs);

5) baseline plus Flumes 4A (1.42 cms; 50 cfs), 5B, and 5C (2.41 cms; 85 cfs) for a total of 12.03 cms (425 cfs);

6) baseline plus Flumes 4A, 5B, and 5C plus saltwater return for a total of 15.99 cms (565 cfs).

In order to achieve baseline conditions, we had the Project close all flumes and the saltwater return at 2300 the night before sampling was to begin. At 0900 on 23 May, we conducted the first survey of transects with baseline conditions. After the initial survey was completed, we opened up Flume 5B, waited an hour and then repeated the transect sampling. Upon completing that set of transects, we waited another hour before repeating the transect sampling again. We followed this procedure until we had sampled the transects four times. At that point, we had intended to open the saltwater return, wait 30 minutes, then resample the transects. Due to time constraints we were forced to postpone that survey.

We had the Locks staff again turn off all flumes and the saltwater return at 2300 on 23 May. On 24 May at 0645, we opened up Flumes 4A, 5B, and 5C, waited an hour and then began our sampling as before, with an hour wait in between surveys. We were in the middle of our 3rd survey when we were informed that the saltwater return had been opened earlier that morning. Since operational conditions had been changed, we were forced to void all sampling we had conducted that morning. We returned on 11 June and completed all surveys with three flumes open as well as with three flumes open plus the saltwater return open. We also completed the survey with one flume and the saltwater return open.

Diffuser Well Video Surveys

On 7, 8 August, we sampled several locations in the diffuser well (Figure 15) with a high-resolution video camera system in order to document the presence or absence of any stranded fish. The diffuser well receives 3.96 cms of water from the salt-water drain and spreads the water out for fish ladder operation. The camera system consisted of the same components used in the flume entrance video monitoring (see above). Sampling periods were chosen to coincide with high tides because we anticipated more slack water areas, or areas of refuge, associated with higher water conditions.

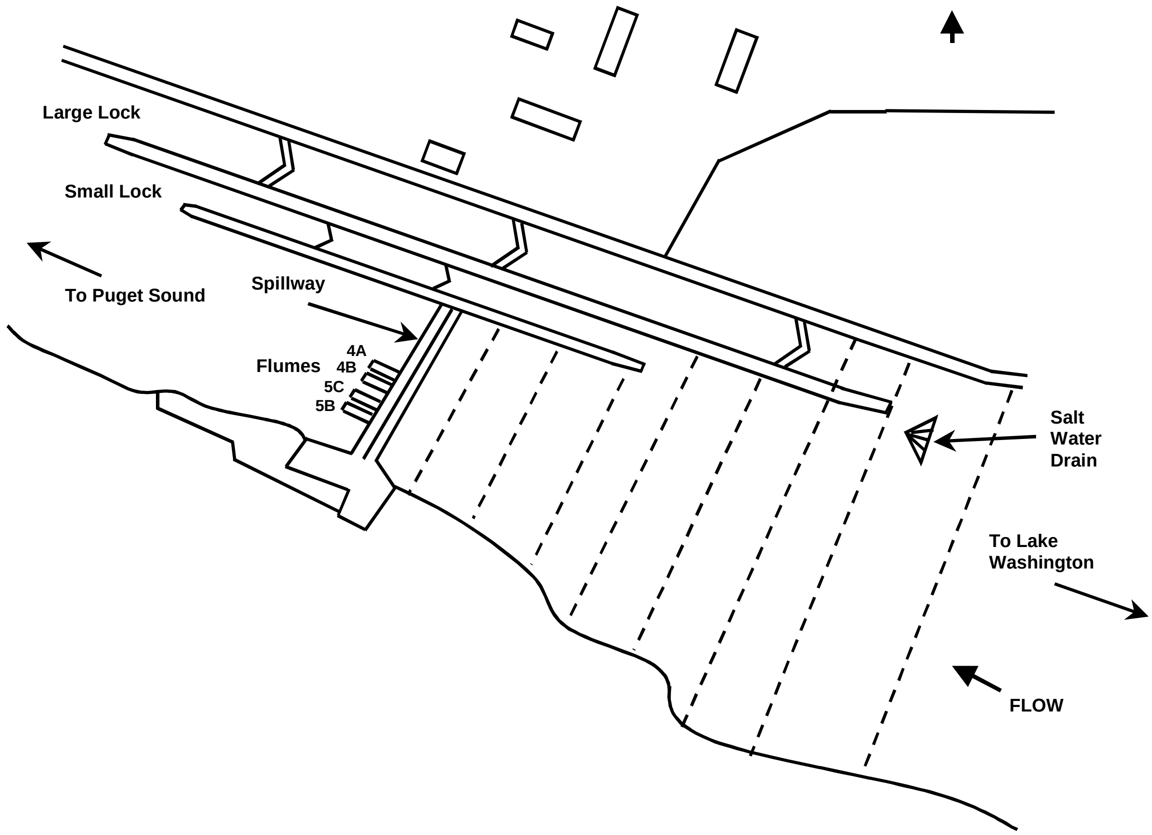

Figure 14. Plan view of the Locks showing approximate location of survey transects sampled using a boat-mounted acoustic Doppler current profiler (transect lines denoted with broken lines). Drawing not to scale.

Our systematic sampling of the diffuser well consisted of deploying the pole-mounted video camera down into the well at locations below each removable metal grate. The camera was oriented perpendicular to the vertically held pole to obtain side aspect images of fish. We attached an underwater flashlight (Sunlight D-4) to provide illumination for the camera. We lowered the camera to the initial sampling station of 0.6 m above the floor. We slowly spun the camera around in a counter-clockwise rotation for 360^{o}, which usually took about one minute. The pole was then raised an additional 0.6 m and the 360^{o} scan was repeated. We repeated this protocol in 0.6 m intervals to just below the water surface. We then removed the camera from the well, replaced the metal grate, and removed the next successive grate to repeat the protocol. We sampled each grate location in this manner, starting at the furthest west grate and successively sampling adjacent locations to the east. We also sampled in a similar fashion the short row of grates just to the north of the initial sampling area. We repeated this entire effort again the second day. We recorded all sampling locations onto Sony T-160 VHS tapes for later review.

Figure 15. Photograph, looking eastward, of the surface grating covering the diffuser well adjacent to the adult fish ladder. The gratings were removed for video surveillance of the well to document presence of stranded juvenile or adult salmonids. The walkway on the left leads up to the spillway deck and the walkway on the right leads down into the adult fish ladder viewing room.

Monitoring for Water Leakage at the Upper Gates of the Large Locks

We investigated the potential for excessive water leakage at the upper gates of the large locks using a boat-mounted ADV unit. On 11 June, we deployed the ADV probe above the upper miter gates at the juncture of the two gates, and along the seams where the gates join the lock walls. The data were collected and processed as reported above in the flume entrance velocity sampling section.

Results

Detectability Modeling

The detectability for sampling in front of the filling culverts at the large lock entranceway was fairly uniform at the elevation of the culvert entrances (from 7.5 to 12 m; Figure 16), although a slight dip is evident between 8.5 and 10 m. The peak in the effective beam angle curve occurred at one meter from the transducer, and the smallest angle was at 2 meters.

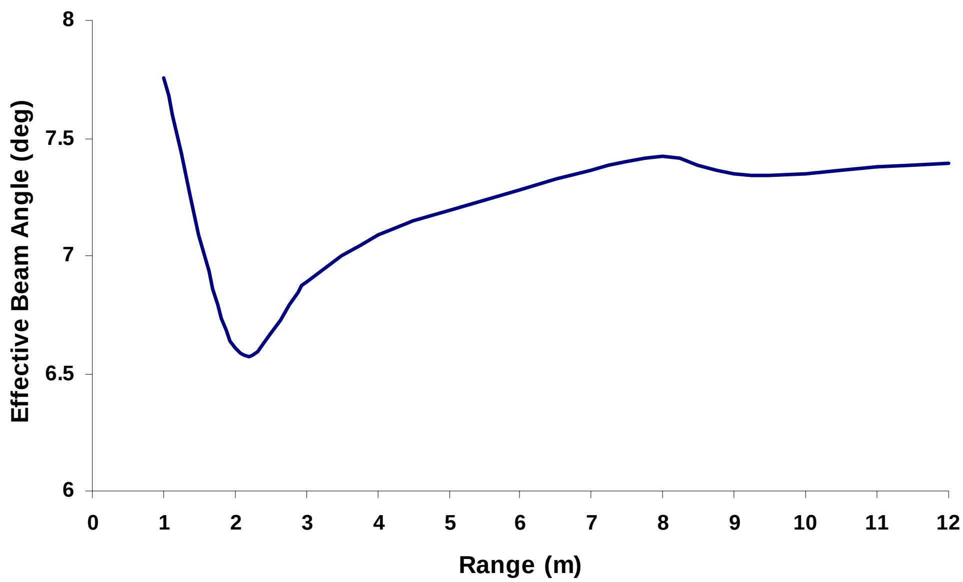

Figure 16. Effective beam angle as a function of range from the down-looking transducers deployed above the culvert entrances in the large lock entranceway.

Culvert Passage

Passage of fish into the filling culverts (entrainment) through the season shows two modes of relatively high entrainment: from 29 May to 20 June and from 24 July to 7 August (Figure 17). Culvert passage, however, was highly variable on a day-to-day basis, and this variability was persistent throughout the entire study period, including the time periods of high entrainment. We estimated that a total of 17,876 fish were entrained into the filling culverts from 24 April through 7 August. Total numbers and passage estimates over time (Figure 17) are based on the sampling of fill events listed in Appendix A. The trend over time of mean number of fish per fill per day (Figure 18) showed modest modes at time periods when total culvert passage peaked (Figure 17), but generally, the pattern was relatively uniform except for on 9 June when mean numbers per fill peaked at 236 fish. This estimate was primarily a function of a single fill event where we estimated 709 fish were entrained. Throughout the entire study period the mean entrainment estimate for a single fill event regardless of valve opening procedure was 25 fish.

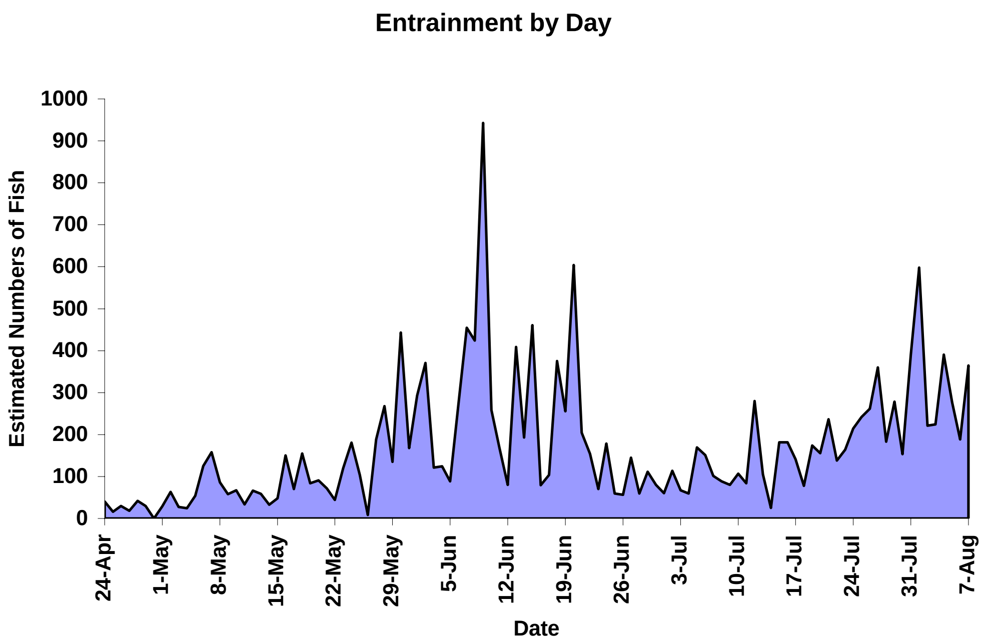

Figure 17. Culvert passage (entrainment) throughout the study period at the Hiram M. Chittenden Locks, in 2001. Estimated numbers of fish are summed totals by day including all sampled fill types and chambers.

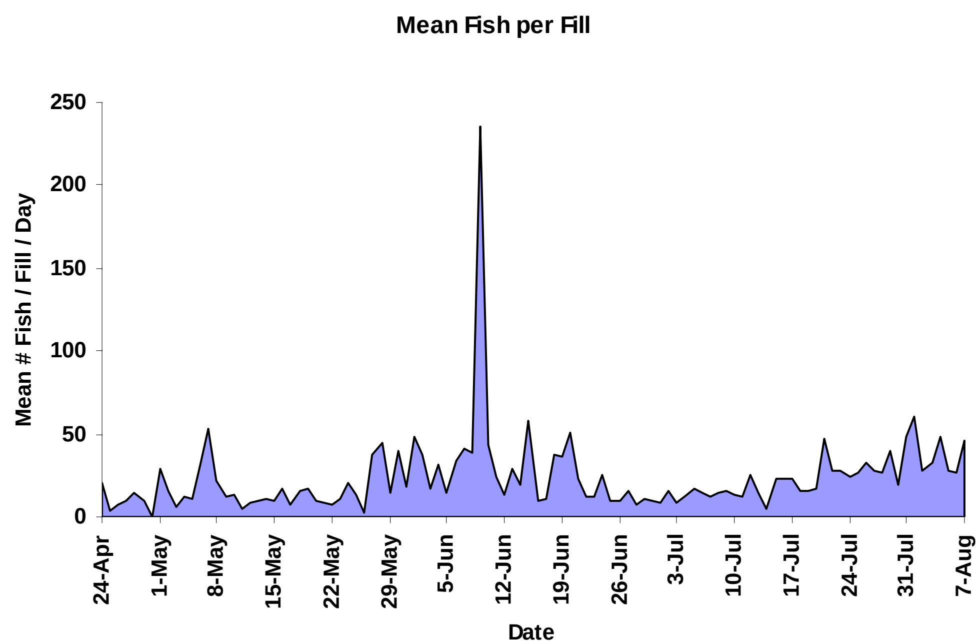

Figure 18. Mean number of entrained fish per fill per day over the study period at the Hiram M. Chittenden Locks, in 2001. Mean numbers include all sampled fill types and chambers.

Estimates of entrainment during intermediate fill types were predominantly higher with full chamber fills than with upper chamber fills (Figure 19). On average, full chamber fill events entrained 22 more fish than did upper chamber fill events. Entrainment estimates between graduated and intermediate fill types varied by day but overall mean numbers of fish per fill type were quite similar (29.4 and 29.8 for graduated and intermediate, respectively; Figure 20). Estimates of entrained fish were similar between the north and south wall filling culverts (Figure 21).

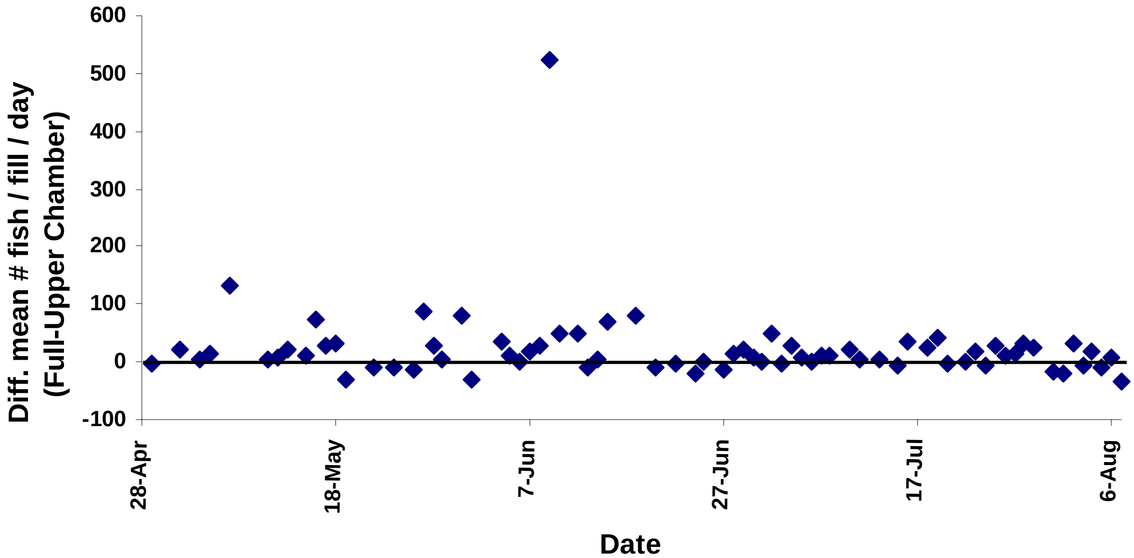

Figure 19. Differences in mean number of entrained fish per fill per day between full and upper chamber fill events.

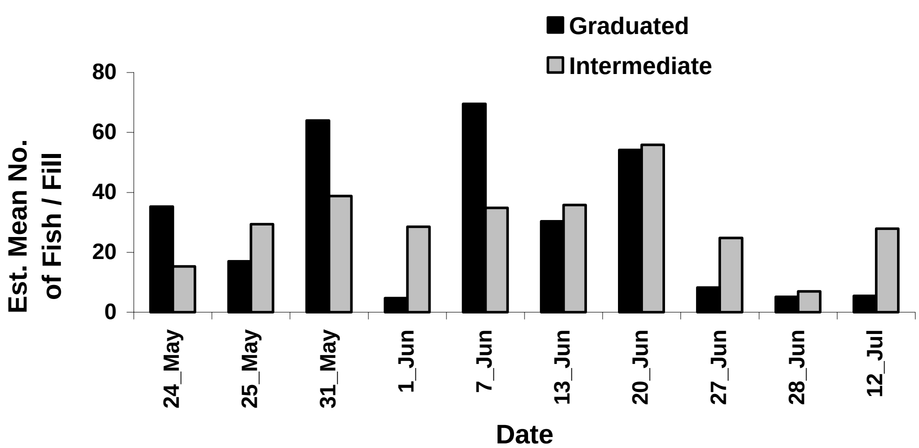

Figure 20. Estimated mean number of fish per fill per day for all days when both graduated and intermediate fill types occurred.

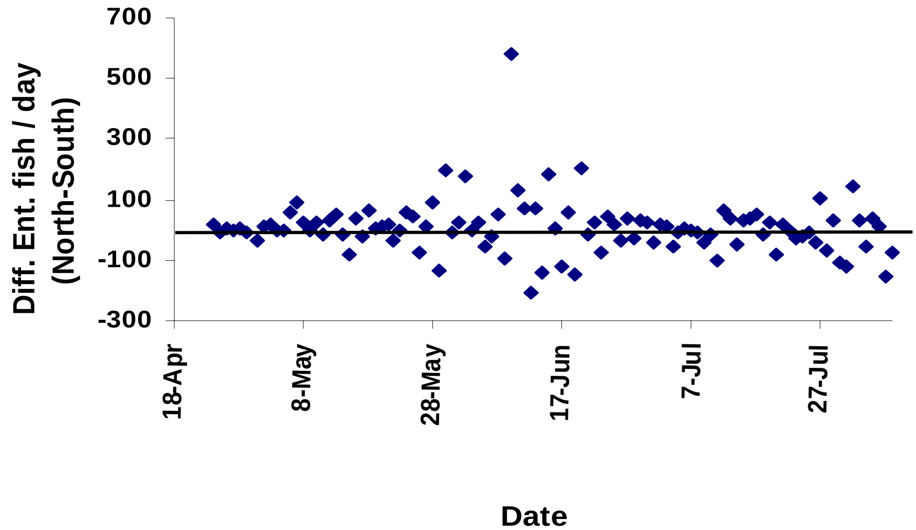

Figure 21. Differences in estimated numbers of entrained fish between north and south wall filling culverts.

Hourly entrainment estimates for upper and full chambers during intermediate fill types were similar in that entrainment generally increased in the early evening hours and peaked in the early morning during upper chamber fills, and between early and mid morning during full chamber fills (Figure 22). Entrainment rates were lowest during the 1900 hour for both upper and full chamber fills.

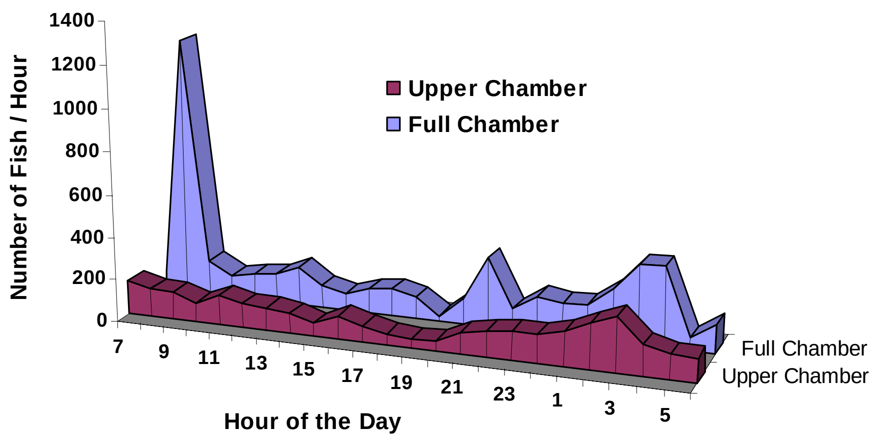

Figure 22. Hourly expanded entrainment estimates for upper and full chamber fill events.

Target Strength Distributions

Comparison of target strength distributions during all fill events among entrained and non-entrained fish clearly shows that larger targets avoided culvert passage more frequently than did smaller targets (Figure 23). The distribution of target strengths of entrained fish shows a bimodal pattern, with the modes located at –49 and –42 dB. Target strength distributions of non-entrained fish were bell-shaped with the mode at –43 dB. The distribution of target strengths broken down by time period reveals that the smallest entrained targets (-48.2 dB) were detected at the onset of the study period (24-30 April) and the largest entrained targets (-44.4 dB) were observed 20-29 June (Figure 24). Across all time periods, mean target strengths were consistently smaller for entrained fish as compared to non-entrained fish. Among time periods regarding non-entrained fish, the largest mean target strength (-42.8 dB) occurred from 1-10 May, and the smallest mean target strength (-45.0 dB) was observed in the period from 31 May to 9 June. Mean target strengths throughout the entire study period were –45.4 and –44.2 dB for entrained and non-entrained targets, respectively. These target strengths are roughly equivalent to 16 and 19 cm long fish, respectively.

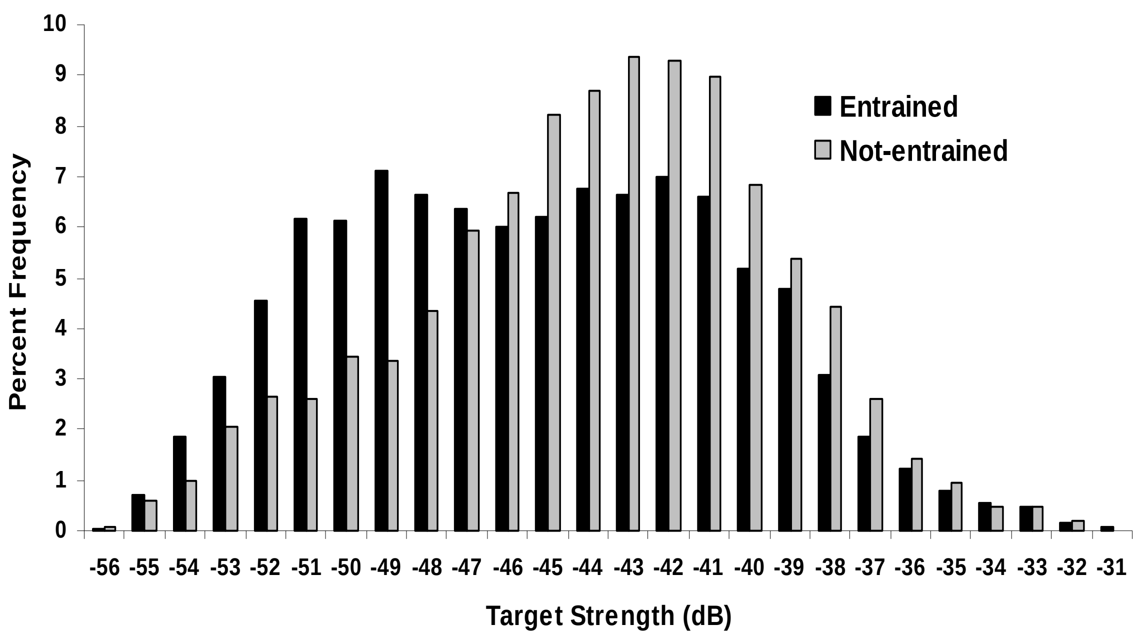

Figure 23. Target strength distributions of entrained and non-entrained fish from 24 April through 7 August, 2001.

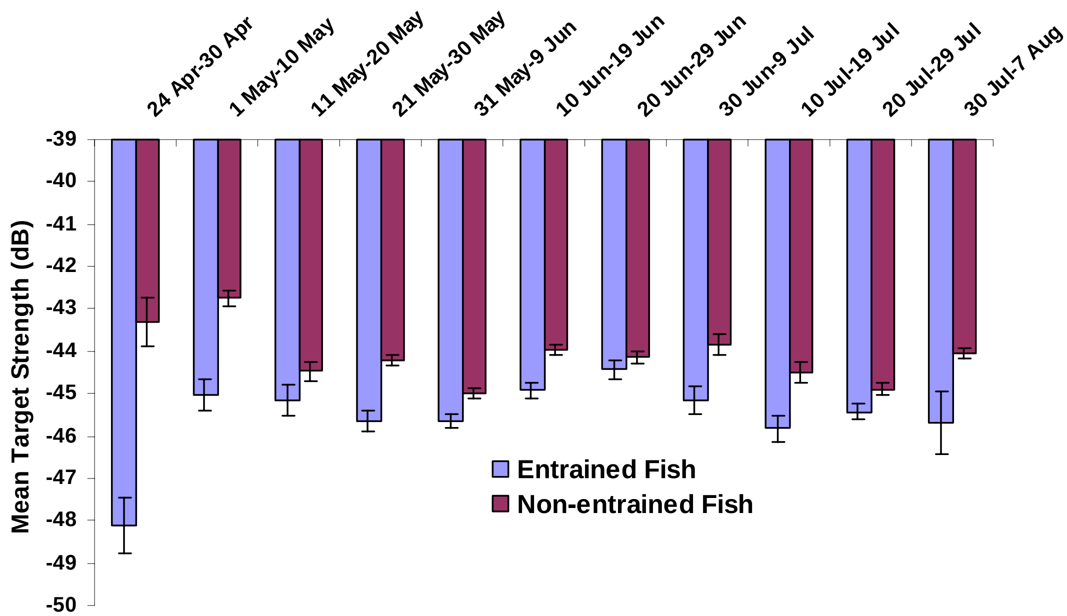

Figure 24. Mean target strengths of entrained and non-entrained fish by time period throughout the study. Error bars represent standard error about the mean.

Vertical Distributions

Before and during fill events and during both daytime (0700-2059) and nighttime (2100-0659) periods, fish were generally distributed within 3 m of the floor or within 2 to 3 m from the water surface, with relatively fewer fish at mid-depths (Figure 25). However, vertical distributions of fish during daytime pre-fill conditions showed fewer fish near the floor than did fill events during the day or either pre-fill or fill events at night. Vertical distribution patterns of entrained fish were different between day and night periods, with daytime entrained fish primarily located between 8.5 to 9.5 m, whereas entrained fish at night were skewed towards deeper strata (10.5 to 11.5 m; Figure 26).

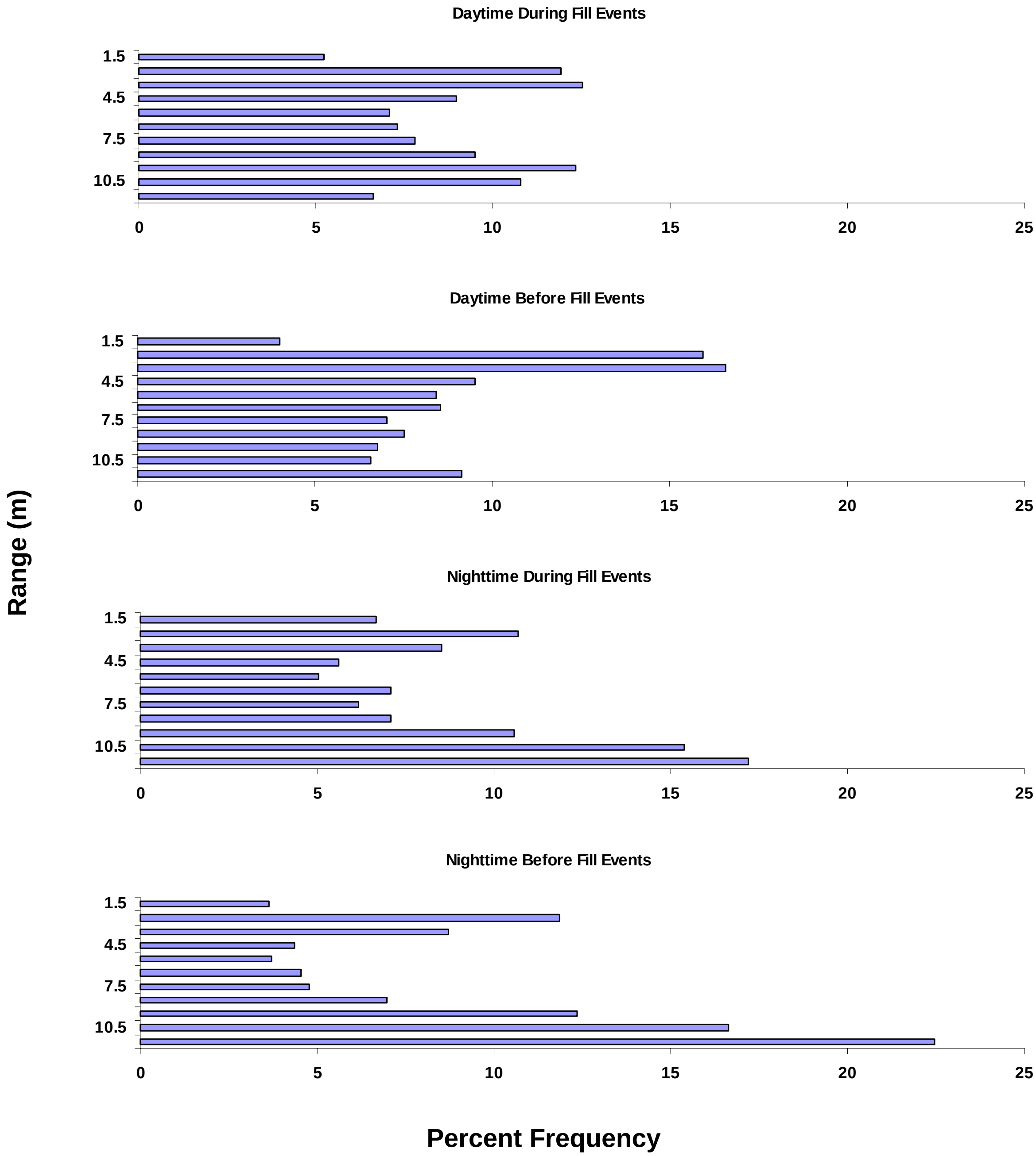

Figure 25. Vertical distributions of fish during the day and at night, before and during fill events in front of the large lock filling culverts.

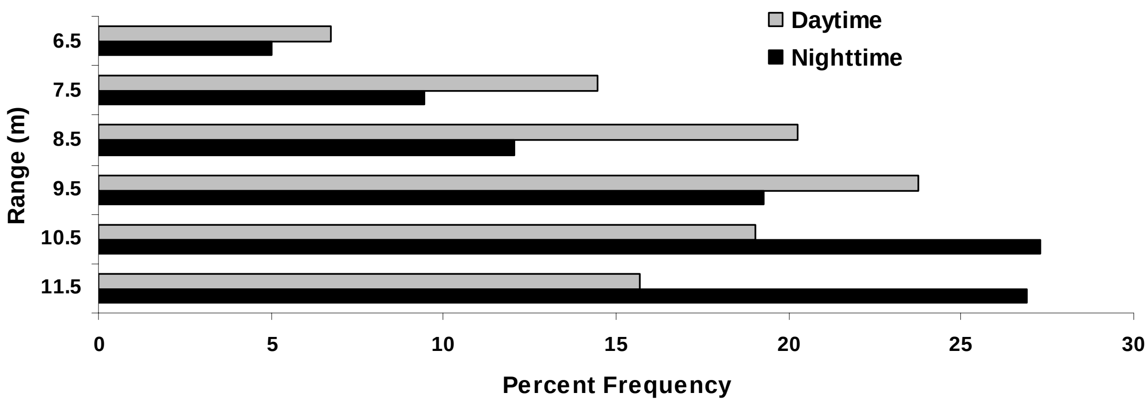

Figure 26. Vertical distributions of entrained fish during daytime and nighttime periods.

Flume Operations and Lake Elevations

Flume operations varied greatly on a daily basis through the 2001 study period (Table 4). A number of factors contributed to the variation of flume operations (see Discussion Section, below), but water conservation was the primary driving function for operating the spillway flumes. The elevation of Lake Washington began to decline towards the end of June (Figure 27) forcing the closure of flumes 4A on 22 June, and 4B on 1 July. In early July, flume operation was limited to 12 hours per day.

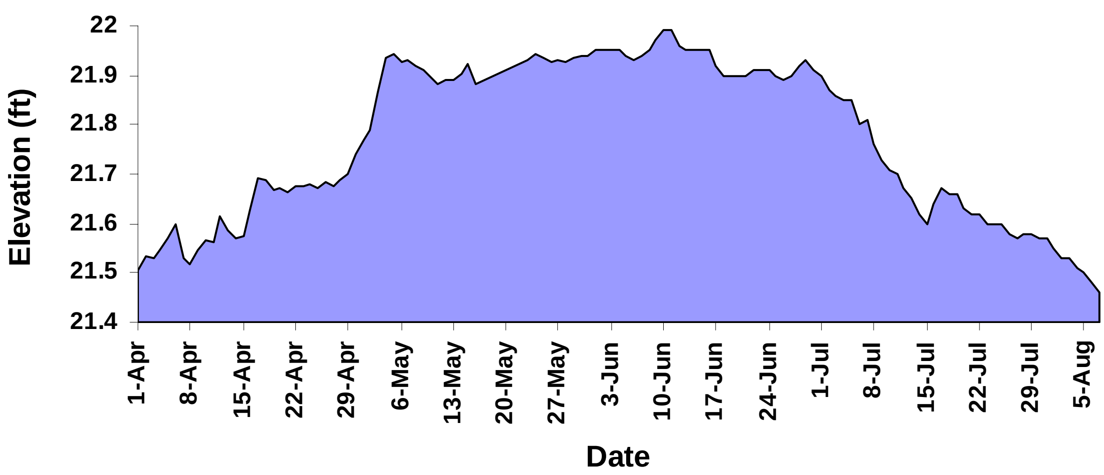

Figure 27. Surface elevation, in feet, of Lake Washington Ship Canal from 1 April -7 August, 2001.

Table 4. List by date of spillway flume operations throughout the 2001 study period. * indicates questionable data (see discussion below).

Date	Spillway Flume Operation and Comments
17-Apr	4A, 4B, 5C initially opened, spill gates 1, 2, 3 open
18-Apr	5C open all day; 4A, 4B all day except 1513-1541; 5B open 1300-2359; counting initialized; spill gates 1,2,3 open
19-Apr	4A, 4B all day; 5B, 5C open and closed intermittently; all open 1100-1700; spill closed
20-Apr	all open all day
21-Apr	all open all day
22-Apr	all open all day
23-Apr	all open all day
24-Apr	all open all day
25-Apr	all open all day
26-Apr	all open all day
27-Apr	4A, 5B, 5C open all day; 4B off at 1400
28-Apr	4A, 5B, 5C open all day; 4B closed
29-Apr	4A, 5B, 5C open all day; 4B closed
30-Apr	5B, 5C open all day; 4A closed 0730-0945; 4B closed
1-May	4A, 5B, 5C open all day; 4B closed
2-May	4A closed 0945-1145; 4A, 4B closed 1550-1640; 4B closed 1700-2359; 5B, 5C open all day
3-May	4A open all day; 4B open 110-2359; 5C open all day; 5B closed 1315-2359
4-May	4A, 4B, 5C open all day; 5B closed
5-May	all open all day; spill gates 1, 2 open
6-May	all open all day; spill gates closed
7-May	all open all day except 5B, 5C closed 1330-1355
8-May	all open all day
9-May	all open all day
10-May	all open all day
11-May	4A, 5C open all day; 5B closed 0830-0915; 4B closed 0915-2359
12-May	4A, 5B, 5C open all day; 4B closed
13-May	4A, 5B, 5C open all day; 4B closed
14-May	4A closed 0925-0940; 4B open 0940-1018; 5B, 5C closed 0943-1006
15-May	4A, 5B, 5C open all day; 4B open 0930-2359; 3 N spill gates open 0900-2359
16-May	all open all day; spill gates closed 0900
17-May	all open all day
18-May	all open all day
19-May	all open all day; spill gates open (#?) 0001
20-May	all open all day; spill gates closed 0600
21-May	4A, 5B, 5C open all day; 4B closed 0800-0935, 0940-2359
22-May	4A, 5B, 5C open 0000-2300; 4B closed
23-May	4A, 5C open 1600-2300; 5B open 1110-2300; 4B closed
24-May	4A, 5B, 5C open 0645-2359; 4B closed
25-May	4A open 0000-0800, 1000-1030, 1130-2359; 5B open 0000-0800, 1130-2359; 5C open 0000-0800, 0930-1000, 1130-2359; 4B closed
26-May	4A, 5B, 5C open all day; 4B closed
27-May	4A, 5B, 5C open all day; 4B closed
28-May	4A, 5B, 5C open all day; 4B closed
29-May	4A open 0000-1030, 1200-1215, 1230-1300, 1415-2359; 5B, 5C open 0000-1030, 1200-1230, 1245-1300, 1415-2359; 4B closed
30-May	4A, 5B, 5C open all day; 4B closed
31-May	4A, 5B, 5C open all day; 4B closed

Table 4. (cont.).

Date	Spillway Flume Operation and Comments
1-Jun	4A, 5B, 5C closed 1000-1100; 4B closed
2-Jun	4A closed 0930-1000; 5B, 5C open all day; 4B closed
3-Jun	4A open all day; 4B open 1310-2359; 5B, 5C closed 1310-1330; spill gate(s)? open
4-Jun	*4A open 0000-1230; 4B open 0000-0100; 5B open all day; 5C open 0000-2230; spill gates closed
5-Jun	4A open 1000-1245; 4B closed; 5B open 0000-0545, 0800-2359; 5C open 0900-1245
6-Jun	4A, 4B, 5C closed; 5B closed 0715-0800, 1400-1530
7-Jun	4A, 4B closed; 5B open 0000-1615; 5C open 1610-2359
8-Jun	* 4A, 4B, 5B closed; 5C open 0600-2200
9-Jun	* 4A, 4B, 5B closed; 5C open 0600-2359
10-Jun	* 4A, 4B open 0545-2300; 5B, 5C open 0000-2300
11-Jun	4A, 5B, 5C open 0700-2359; 4B open 1230-2359; spill gate 3 open 1230
12-Jun	4A closed 1215-1230, 1245-1300; 4B closed 1245-1300; 5B, 5C closed 1200-1230, 1245-1300; spill gates 1-3 open ?-1210
13-Jun	all flumes open all day
14-Jun	all flumes open all day
15-Jun	4A, 4B closed 1515-1530; 5B, 5C open all day
16-Jun	all flumes open all day
17-Jun	all flumes open 0000-2300
18-Jun	* 4A, 4B closed; 5B, 5C open 1220-1700
19-Jun	* 4A, 4B closed; 5B, 5C open 0700-2300
20-Jun	*4A, 4B closed; 5B, 5C open 0700-2000
21-Jun	*4A, 4B closed; 5B, 5C open 0500-2100
22-Jun	4A, 4B open 0800-1100; 5B, 5C open 0500-2359
23-Jun	*4A, 4B closed (**4A for season**); 5B, 5C open all day
24-Jun	4B closed; 5B, 5C open all day
25-Jun	4B closed; 5B, 5C open all day except for 30 mins
26-Jun	4B closed; 5B, 5C open all day
27-Jun	4B open 1400-1900; 5B, 5C open all day
28-Jun	4B open 0600-1800; 5B, 5C open all day
29-Jun	4B open 0600-1845; 5B, 5C open all day
30-Jun	4B open 0600-1800; 5B, 5C open all day
1-Jul	4B open 0545-1800; 5B, 5C open 0000-2300
2-Jul	**4B closed for season**; 5B open 0700-2359; 5C open 1430-2359
3-Jul	5B, 5C open all day
4-Jul	*5B, 5C open 0500-2100
5-Jul	*5B, 5C open 0500-2100
6-Jul	*5B, 5C open 0500-2359
7-Jul	5B, 5C open all day
8-Jul	5B, 5C open all day
9-Jul	*5B, 5C open 0000-1800
10-Jul	5B, 5C open 0600-1800
11-Jul	5B, 5C open 0600-1800
12-Jul	5B, 5C open 0600-1800
13-Jul	5B, 5C open 0600-1800
14-Jul	5B, 5C open 0600-1800
15-Jul	5B, 5C open 0600-1800
16-Jul	5B open 1200-1800; 5C open 0600-1200
17-Jul	5B open 0600-1800; **5C closed for season**
18-Jul	5B open 0600-1800

Table 4. (cont.).

Date	Spillway Flume Operation and Comments
19-Jul	5B open 0600-1800
20-Jul	5B open 0600-1800
21-Jul	all closed
22-Jul	5B open 0600-1800
23-Jul	5B open 0600-1800
24-Jul	5B open 0600-1800
25-Jul	5B open 0600-1800
26-Jul	5B open 0945-1330, 1500-1800
27-Jul	5B open 0600-1800
28-Jul	5B open 0600-1800
29-Jul	5B open 0600-1800
30-Jul	5B open 0600-1800
31-Jul	5B open 0600-1800
1-Aug	5B open 0600-1800
2-Aug	5B open 0600-1800
3-Aug	5B open 0600-1800
4-Aug	5B open 0600-1800
5-Aug	5B open 0600-1800
6-Aug	5B open 0600-1800
7-Aug	*5B open 0000-1800
8-Aug	**5B closed for season**

Flume Passage

Daily flume passage during the 2001 study period shows a bimodal pattern, with the initial mode occurring in early to mid May, and the second and primary mode occurring mid to late June (Figure 28). We estimated the total number of fish passed over the flumes during daylight hours from 18 April to 5 August to be 740,153. The peak daily passage occurred on 19 June when 53,550 were estimated to pass the Project via the flumes. An estimated 31,815,855 m^3 of water passed over the flumes during daylight hours through the study period, resulting in on average 0.023 fish per m^3, or approximately 2.3 fish per 100 m^3 of water. For selected days when all flumes were operational and passage estimates were obtained, Flume 4A was shown to pass most fish per water volume more frequently relative to the other flumes (Figure 29). Based on the Ryan-Einot-Gabriel-Welsch (SAS Institute 1990) multiple range test, Flume 4A passed significantly greater numbers of fish per flume volume than all the other flumes ($P=0.004$; 3 degrees of freedom).

Mean hourly estimates of smolt passage over the flumes peaked at midday with about 760 fish per hour and were lowest during the 0700 hr with 155 fish per hour (Figure 30). Over 1200 fish per hour were estimated during 1900 hr, but this estimate is misleading since the sample size was small (n=2 hours).

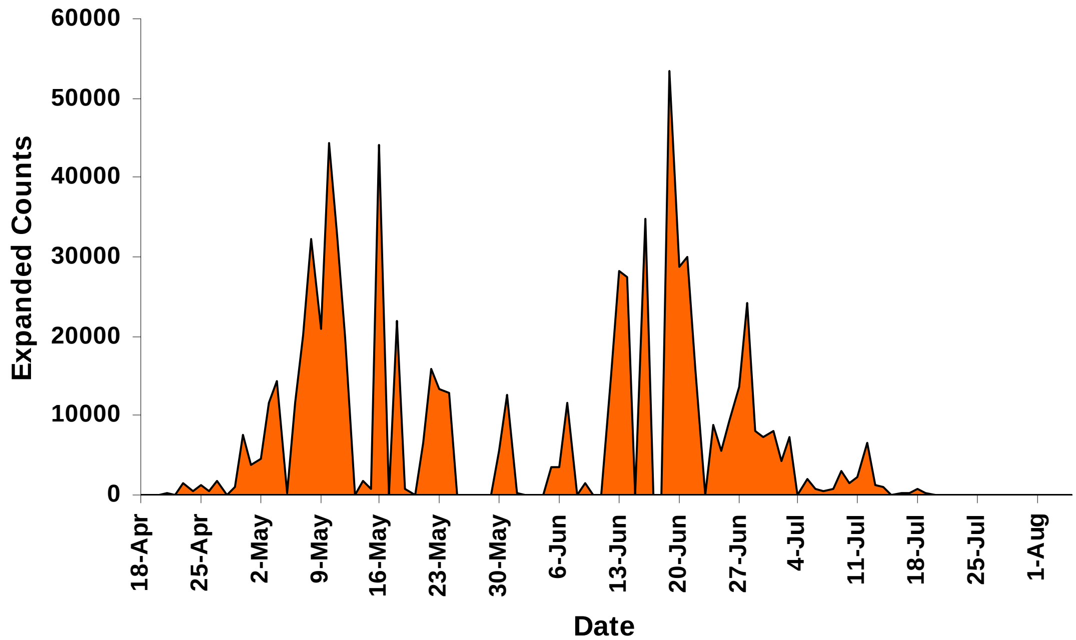

Figure 28. Run timing through the Locks based on expanded counts at the spillway flumes from 18 April through 5 August, 2001.

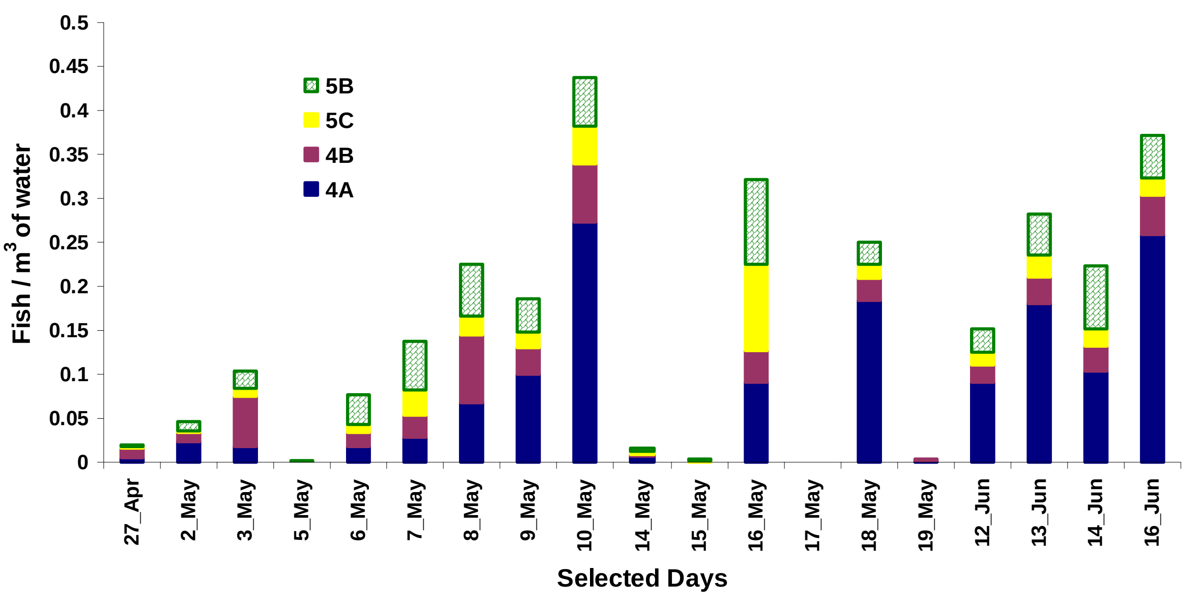

Figure 29. Estimated fish passed per m^3 of water per flume for selected days when all spillway flumes were operational.

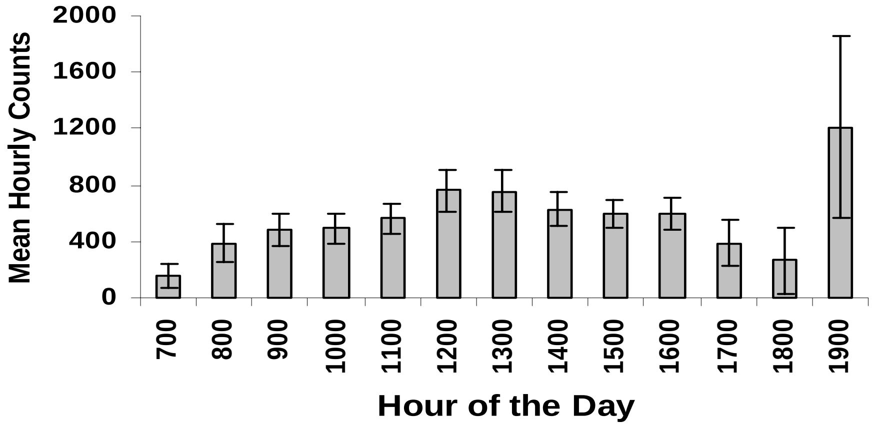

Figure 30. Mean hourly estimates of spillway flume passage during daylight hours from 18 April through 5 August, 2001. Error bars represent standard error about the mean.

Relative Project Fish Passage

Fish passed through the Locks in much greater proportions over the flumes than through the large lock filling culverts, especially during periods when at least 7 mps (about 250 cfs) passed the flumes (Figure 31). As flume volume dropped in early to mid July, culvert entrainment comprised a greater portion of Project fish passage relative to flume-passed fish. Prior to 5 July 96% of fish passed via the flumes relative to culver-entrained fish. After 4 July relative fish passage over the flumes dropped to 53%.

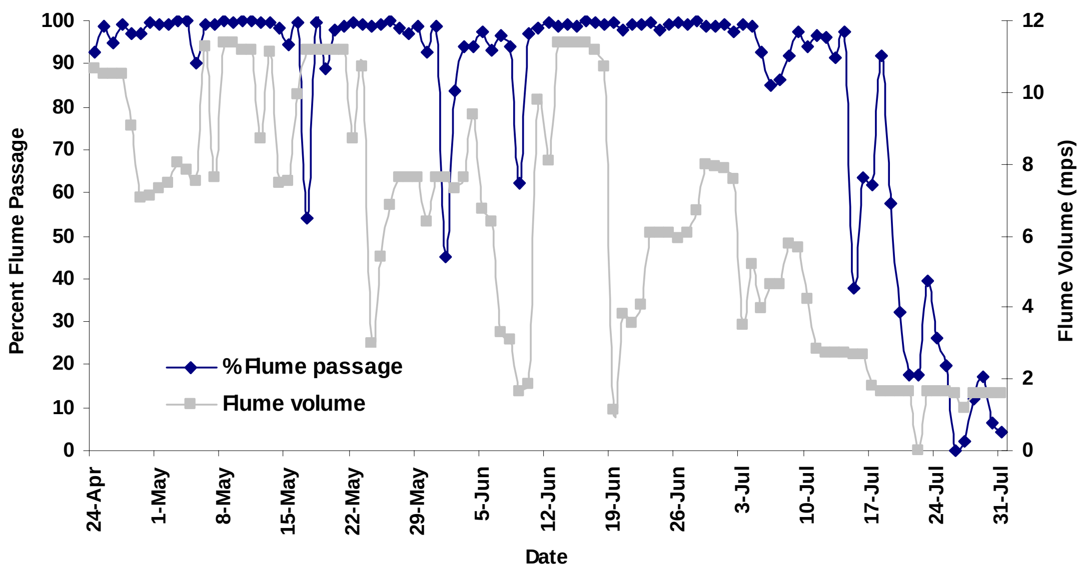

Figure 31. Relative flume passage and flume volume during the 2001 study period.

Smolt Presence in the Small Lock Entranceway

Efforts to document smolt presence in the small lock entranceway using an underwater video camera system yielded no observations of juvenile salmon in four out of the five sampling days. However, on 20 June we observed two groups of juvenile salmon between 4.5 and 6 m below the water surface near the north culvert during a fill event. About six individuals were observed at the beginning of the fill and about 10 individuals were observed at the end of the fill. Although the fish were very near the culvert entrance, no fish were seen to be entrained by the filling flows into the small lock chamber.

Video Sampling at Entrance to Flume 5B

The following qualitative observations were based on processing video data acquired at the entrance to Flume 5B:

1. The vast majority of all juvenile salmonids passed into the flume in a tail-first orientation.

2. Of the fish observed in head-first orientation, the majority of them were tail-first until entering the mouth of the flume.

3. Tail-first fish generally passed into the flume at slower rates than the flume entrance flows.

4. The few fish that were observed in head-first orientation as they entered the field-of-view passed into the flume at about the same rate as the flume entrance velocities.

5. All observed juvenile salmonids were seen in profile (i.e., no fish were seen broad-side to the flow).

6. Group sizes of observed juvenile salmon in the camera's field-of-view ranged from fewer than 10 to more than 100 individuals.

7. Generally, the most frequently observed group sizes were between 10-25 or 25-50 individuals.

8. Group proportions that entered the flume varied greatly among and within days and among group sizes. However, generally greater proportions of juvenile salmonid groups were observed to enter the flume earlier in the study period compared to later in the study period.

9. Groups or portions of fish groups that were observed not to enter the flume typically avoided the flume entrance by either swimming laterally towards the north or swimming down below the entrance.

10. Adult salmon were observed on three occasions: 13 June, a single adult appeared to enter the flume; 14 July, a single adult came in and out of view

but did not enter the flume; 18 July, two adults were observed and one of the two entered the flume tail-first.

11. There were no observed predator-prey interactions.

12. Two non-salmonid fish were observed. Their species identities are unknown but they resembled cyprinids.

Flume Entrance Velocity Characterization

Near surface downstream velocities immediately upstream of the flume entrances were slightly greater in front of Flume 5B (5B) as compared to 5C (Figure 32 – upper plot). The stream traces near the surface indicate gradually accelerating flow towards the flume entrances in the center of the flow volume and a shedding away from the structures along the edges. At elevation 6.4 m, the high velocity area in front of 5B broadens slightly to the south, and the maximum velocities at the entrance to 5C equaled those observed at 5B (Figure 32 – center plot). The high velocity areas in front of both flumes broaden laterally at elevation 6.2 m, and the stream traces indicate similar prevailing directional flow as the previous elevations (Figure 32 – lower plot). Velocity conditions remained relatively unchanged at elevations 6.0 and 5.8 m (Figure 33 – upper and center plots), but at elevation 5.6, an upstream flow component is evident on the north side of the entrance to 5B (Figure 33 – lower plot). Additionally, the area of high velocity in front of 5C diminishes from east to west at elevation 5.6 m. At elevation 5.3 m (just below the floor of the flume entrances), except for two small pockets of high downstream velocity, the flow is either in an upstream direction or stagnant (Figure 34 – upper plot). There were pockets of both upstream and downstream velocities in front of 5B at elevation 5.1 m, but none evident in front of 5C (Figure 34 – center plot). The flow field was characterized by stagnant to very slow moving water at elevation 4.9 m (Figure 34 – lower plot), but velocities increased at elevations 4.7 and 4.4 m (Figure 35).

From a side view perspective of horizontal and vertical flow field characteristics in front of the flumes, no discernible velocity patterns were evident at the north edge of the sampling area (Figure 36). Moving southward to a cross section near to the north edge of 5C, a region of increased velocity occurs near the opening of the flume in the horizontal direction and below and in front of the flume in the vertical direction (Figure 37). A cross-sectional plot of the flow field bisecting the entrance to 5C shows increasing velocity contours on the horizontal plane the closer to the flume mouth, with moderate (0.3 m/s) velocities extending about 1.75 m upstream (Figure 38 – upper plot). The vertical velocity component at this same cross section peaks in the area just below and immediately in front of the bottom of the flume mouth, and the upward velocity field extends about 1 m upstream of the flume mouth (Figure 38 – lower plot). At this same location, downward velocities are evident near the surface just upstream of the flume mouth. There is little apparent change in both horizontal and vertical flow fields at the cross section near the south edge of the 5C (Figure 39) as compared to the previous cross section (Figure 38). The cross section of the flow field between the flume openings indicates the presence of a low velocity patch in the horizontal plane extending from the structure upstream to about 1 m (Figure 40 – upper plot). The vertical flow field at this location diminished in magnitude from the previous cross section, but maintained roughly the same size and shape (Figure 40 – lower plot). The horizontal flow field at the cross section located near the north edge of 5B shows highest velocities in the middle third of the flume entrance and low velocity contours extending out about 2 m from the structure (Figure 41 – upper plot). An area of still water occurs at the floor of the entrance to 5B. Vertical velocities at this location peak at the floor of the entrance to 5B to about 0.3 m below the floor (Figure 41 – lower plot). As observed in front of 5C (Figures 37-39), an area of downward velocity is evident near the surface in front of 5B. The next cross section to the south indicates flow characteristics similar to the previous location with the exception of an increase in magnitude of horizontal velocity at the entrance to 5B, and an upstream flow component apparent near the entrance floor (Figure 42). Flow field velocities progressively diminished in both the horizontal and vertical planes in the remaining cross sections (Figures 43-45).

Based on a cross section in front of Flume 5B, the log boom's influence on the current velocities was to extend the moderate (0.6 m/s) downstream flow component upstream about 0.5 m, and decrease the magnitude of the vertical component by one half (compare plots in Figure 46 with log-boom in place with plots in Figure 38 without the log boom). However, the data used to create the contour plots with the log boom treatment are incomplete due to the obstruction of the sampling area by the log boom itself (see Discussion below).

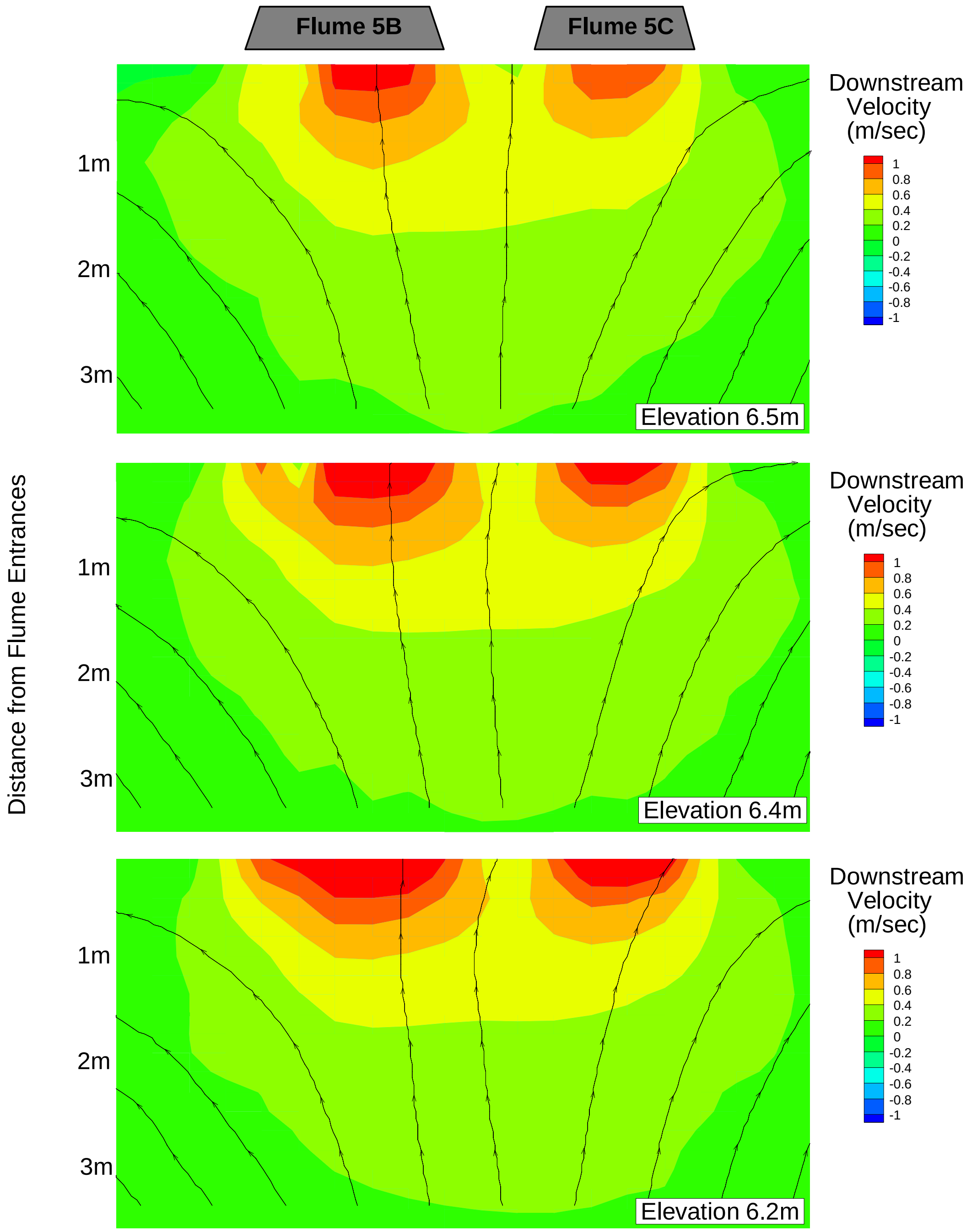

Figure 32. Plan view of downstream velocity contours at three elevations upstream of the flume entrances at Spillbay 5. Stream traces represent downstream and lateral components of flow. Flow is from bottom to top (east to west).

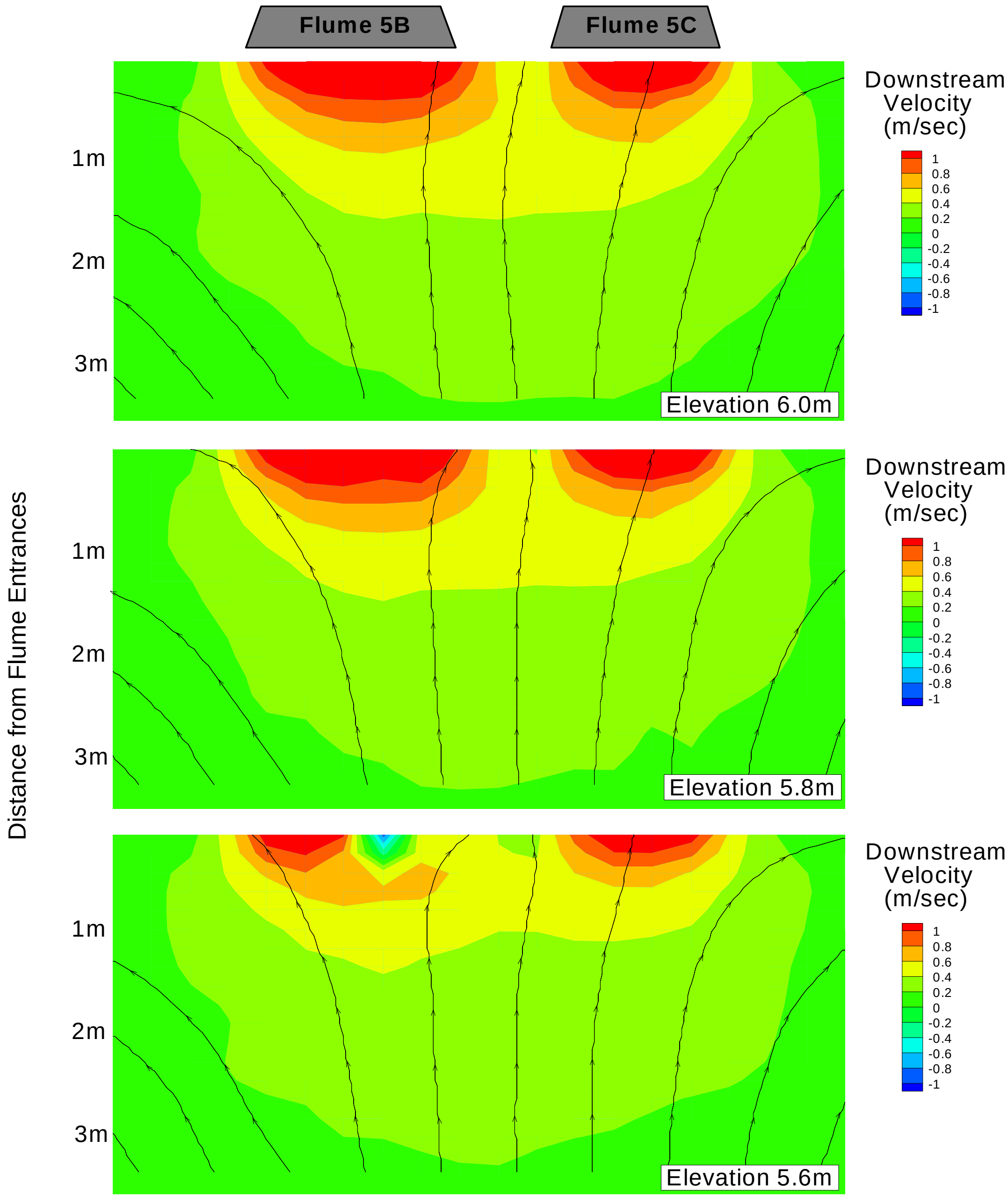

Figure 33. Plan view of downstream velocity contours at three elevations upstream of the flume entrances at Spillbay 5. Stream traces represent downstream and lateral components of flow. Flow is from bottom to top (east to west).

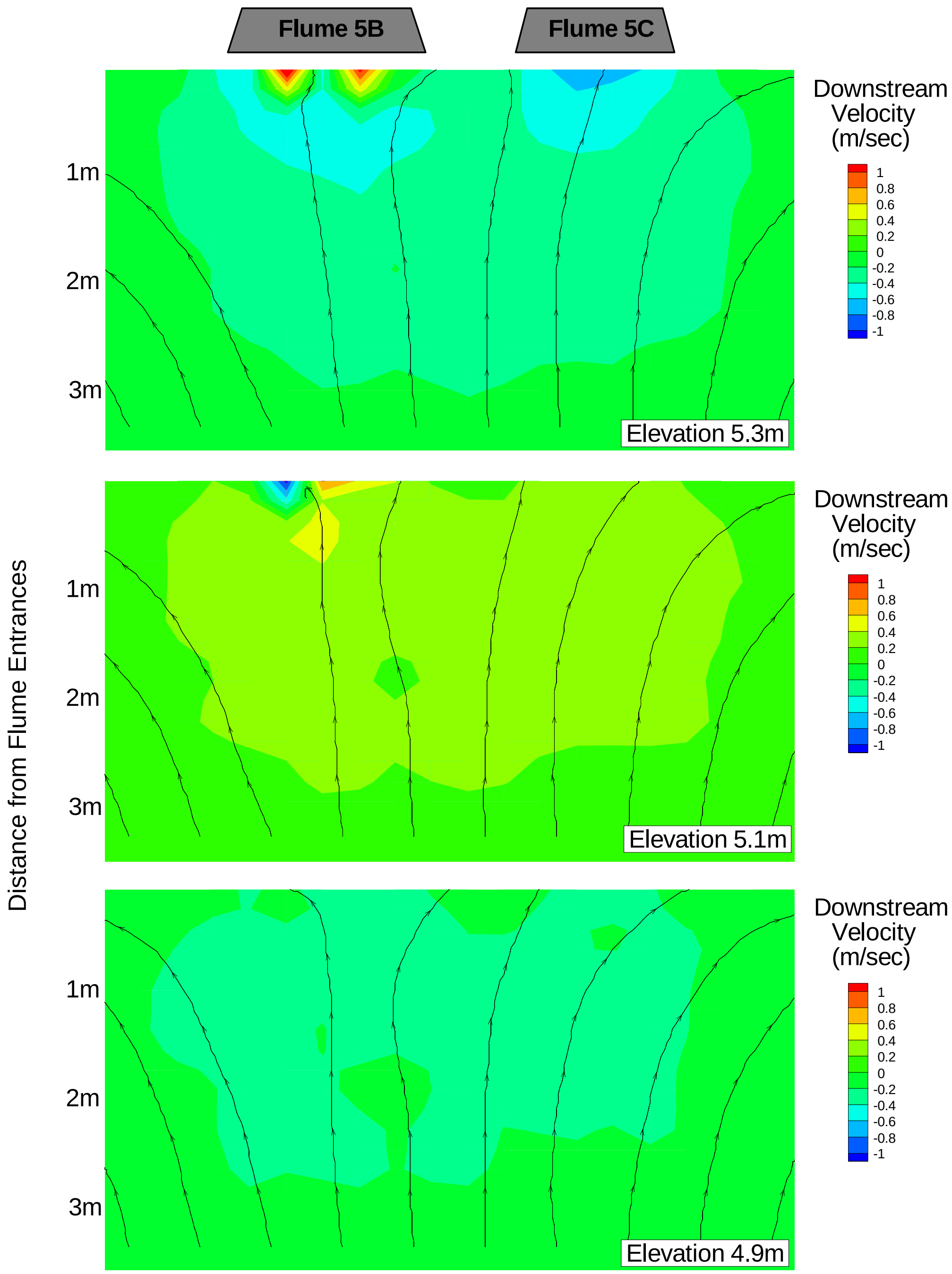

Figure 34. Plan view of downstream velocity contours at three elevations upstream of the flume entrances at Spillbay 5. Stream traces represent downstream and lateral components of flow. Flow is from bottom to top (east to west).

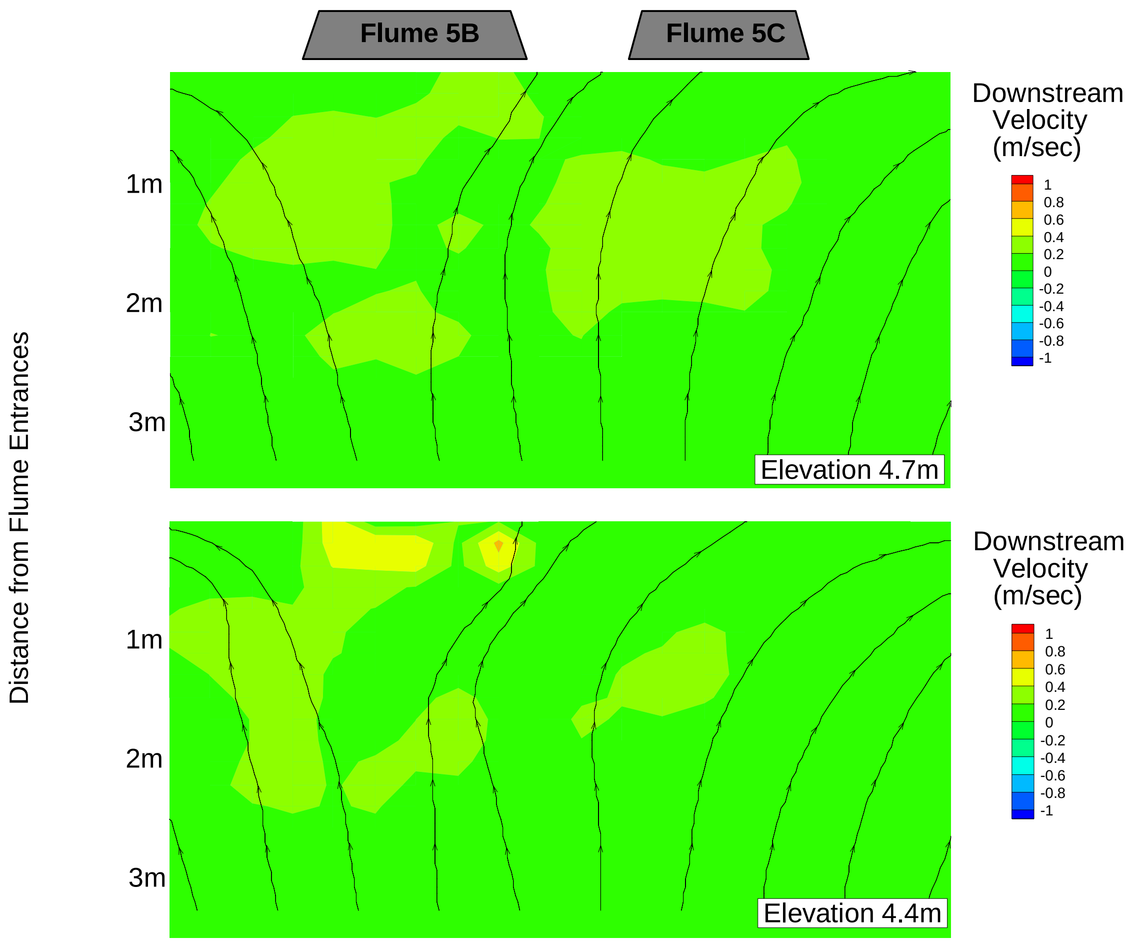

Figure 35. Plan view of downstream velocity contours at two elevations upstream of the flume entrances at Spillbay 5. Stream traces represent downstream and lateral components of flow. Flow is from bottom to top (east to west).

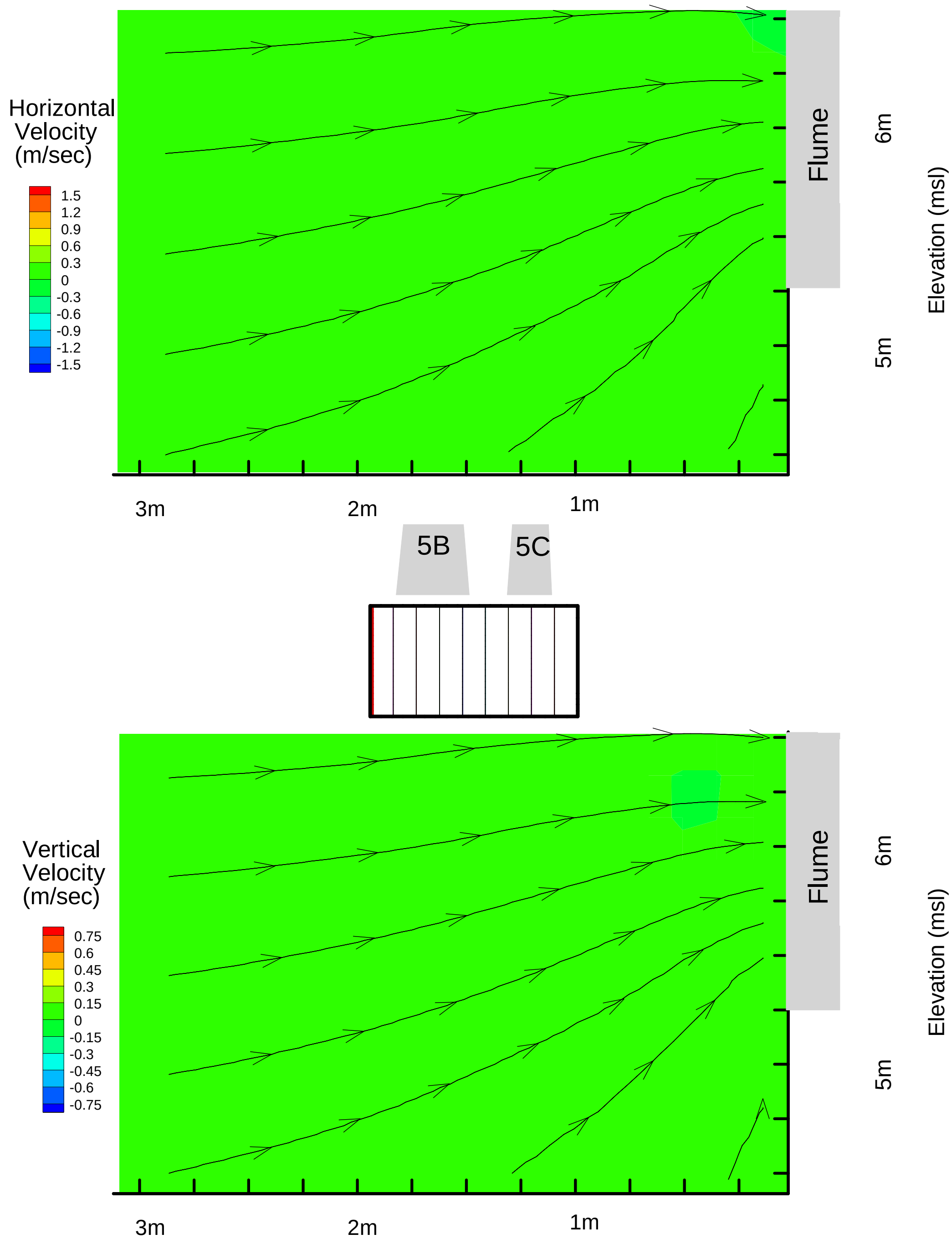

Figure 36. Cross-sectional view of flow field near the entrances of flumes 5B and 5C, showing horizontal (top) and vertical flow velocity components. Cross-sectional slice location shown in figure between plots. Flow is from left to right (east to west).

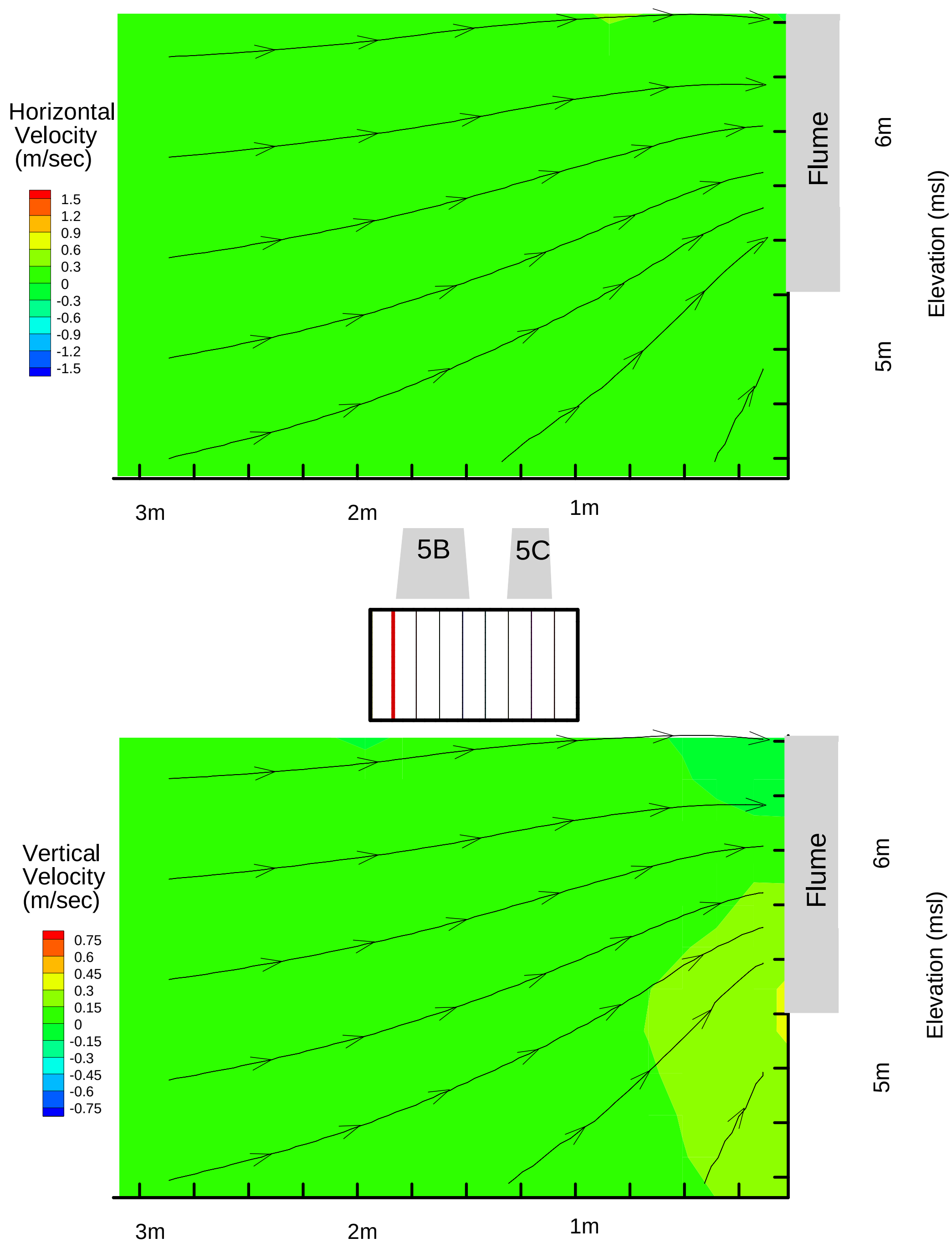

Figure 37. Cross-sectional view of flow field near the entrances of flumes 5B and 5C, showing horizontal (top) and vertical flow velocity components. Cross-sectional slice location shown in figure between plots. Flow is from left to right (east to west).

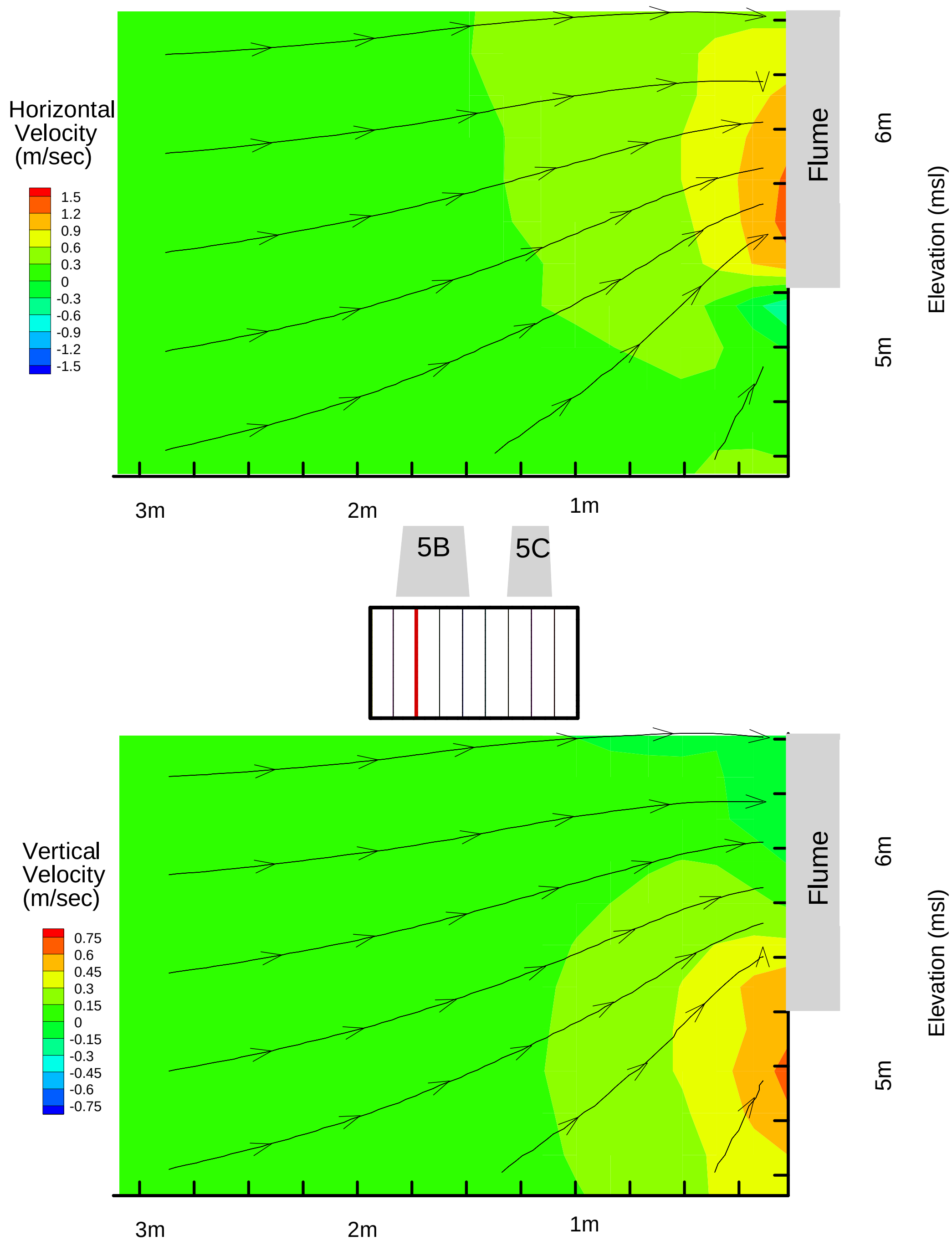

Figure 38. Cross-sectional view of flow field near the entrances of flumes 5B and 5C, showing horizontal (top) and vertical flow velocity components. Cross-sectional slice location shown in figure between plots. Flow is from left to right (east to west).

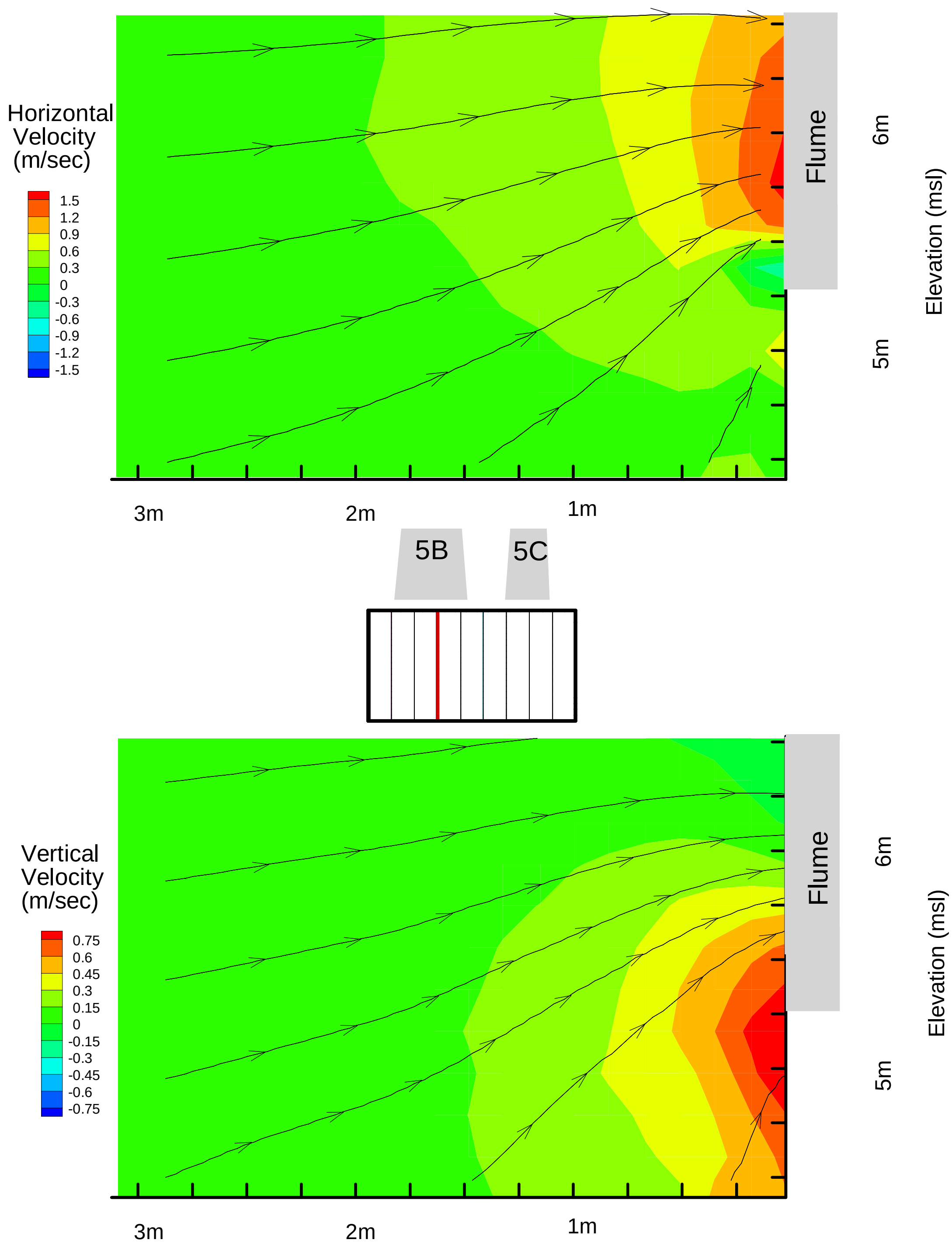

Figure 39. Cross-sectional view of flow field near the entrances of flumes 5B and 5C, showing horizontal (top) and vertical flow velocity components. Cross-sectional slice location shown in figure between plots. Flow is from left to right (east to west).

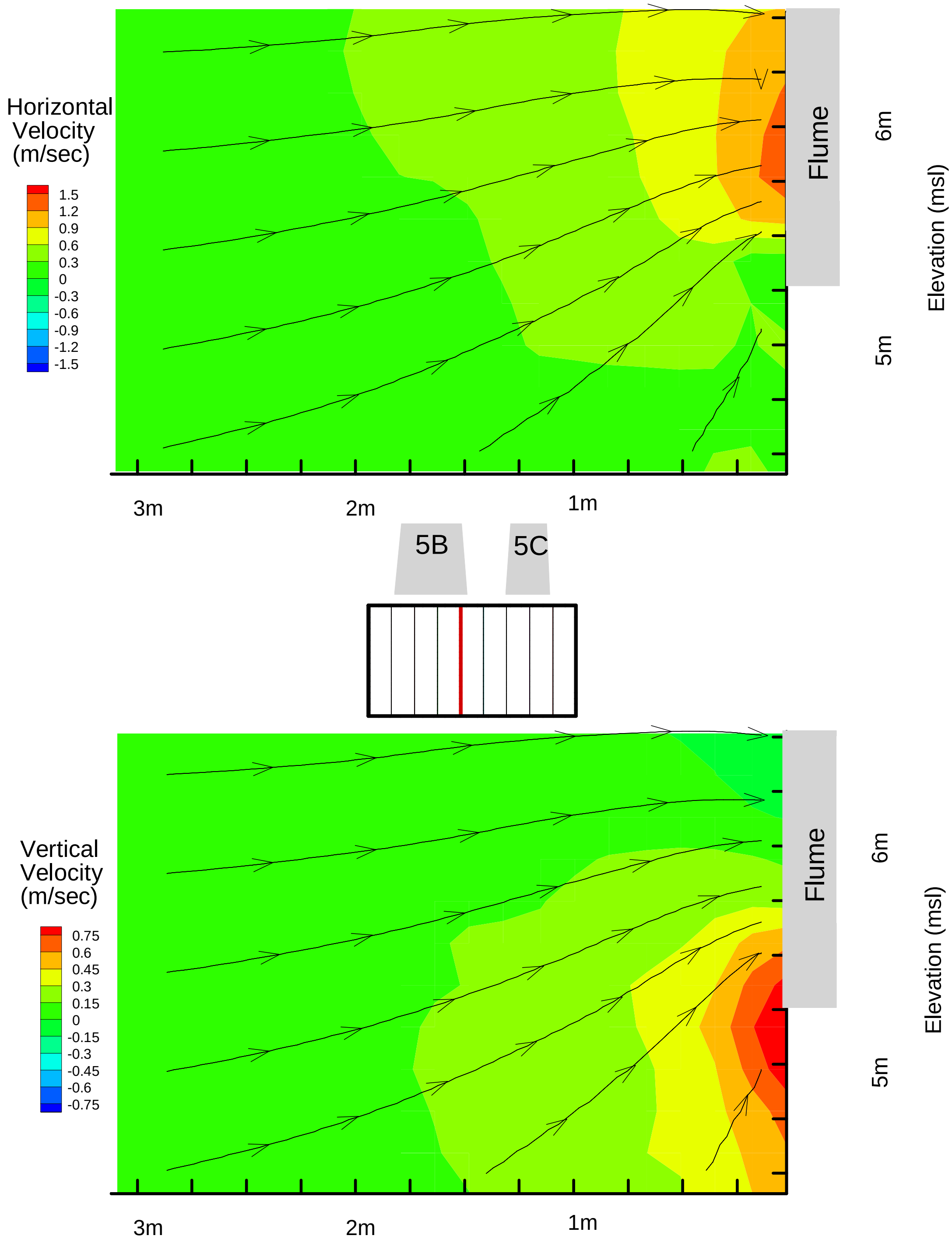

Figure 40. Cross-sectional view of flow field near the entrances of flumes 5B and 5C, showing horizontal (top) and vertical flow velocity components. Cross-sectional slice location shown in figure between plots. Flow is from left to right (east to west).

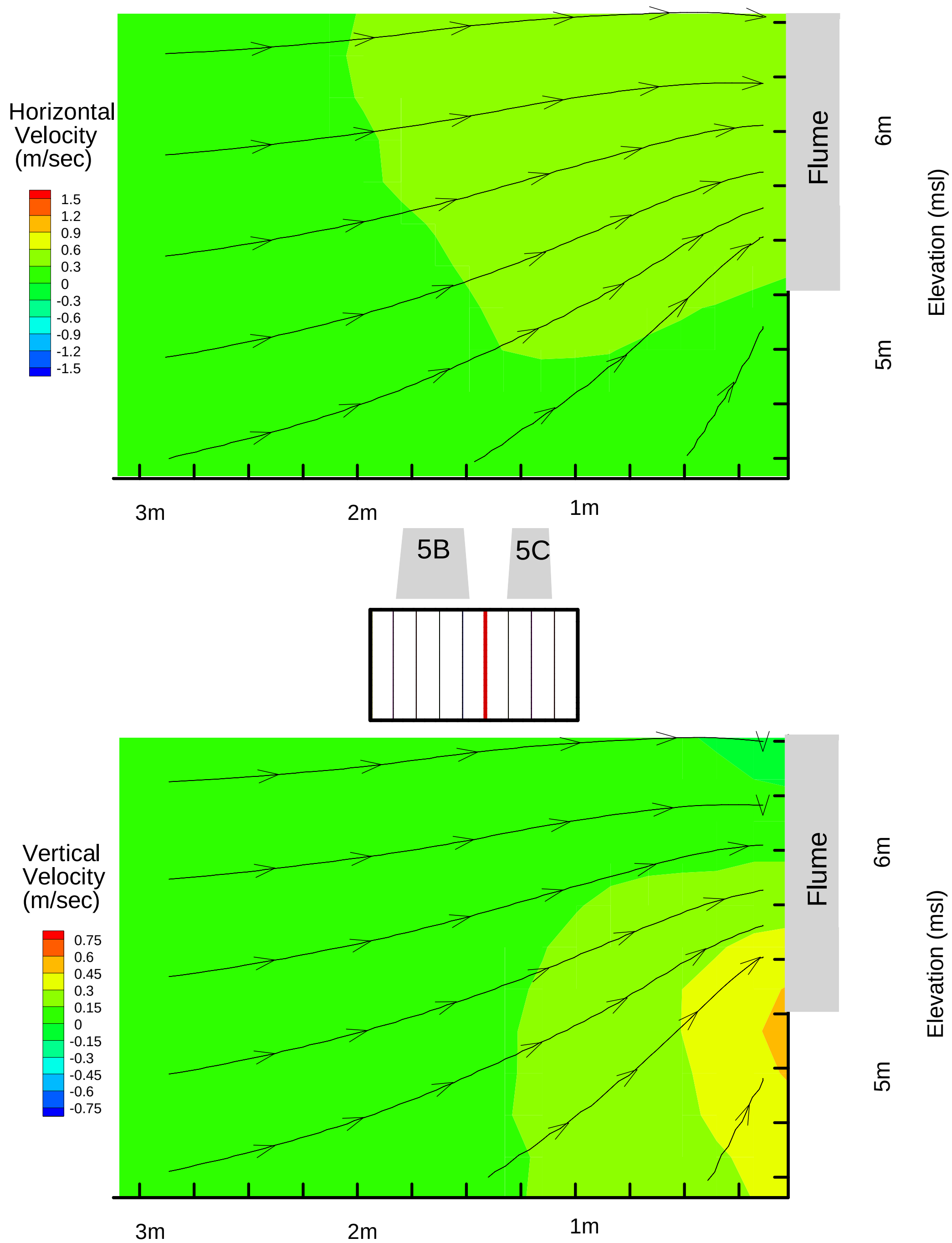

Figure 41. Cross-sectional view of flow field near the entrances of flumes 5B and 5C, showing horizontal (top) and vertical flow velocity components. Cross-sectional slice location shown in figure between plots. Flow is from left to right (east to west).

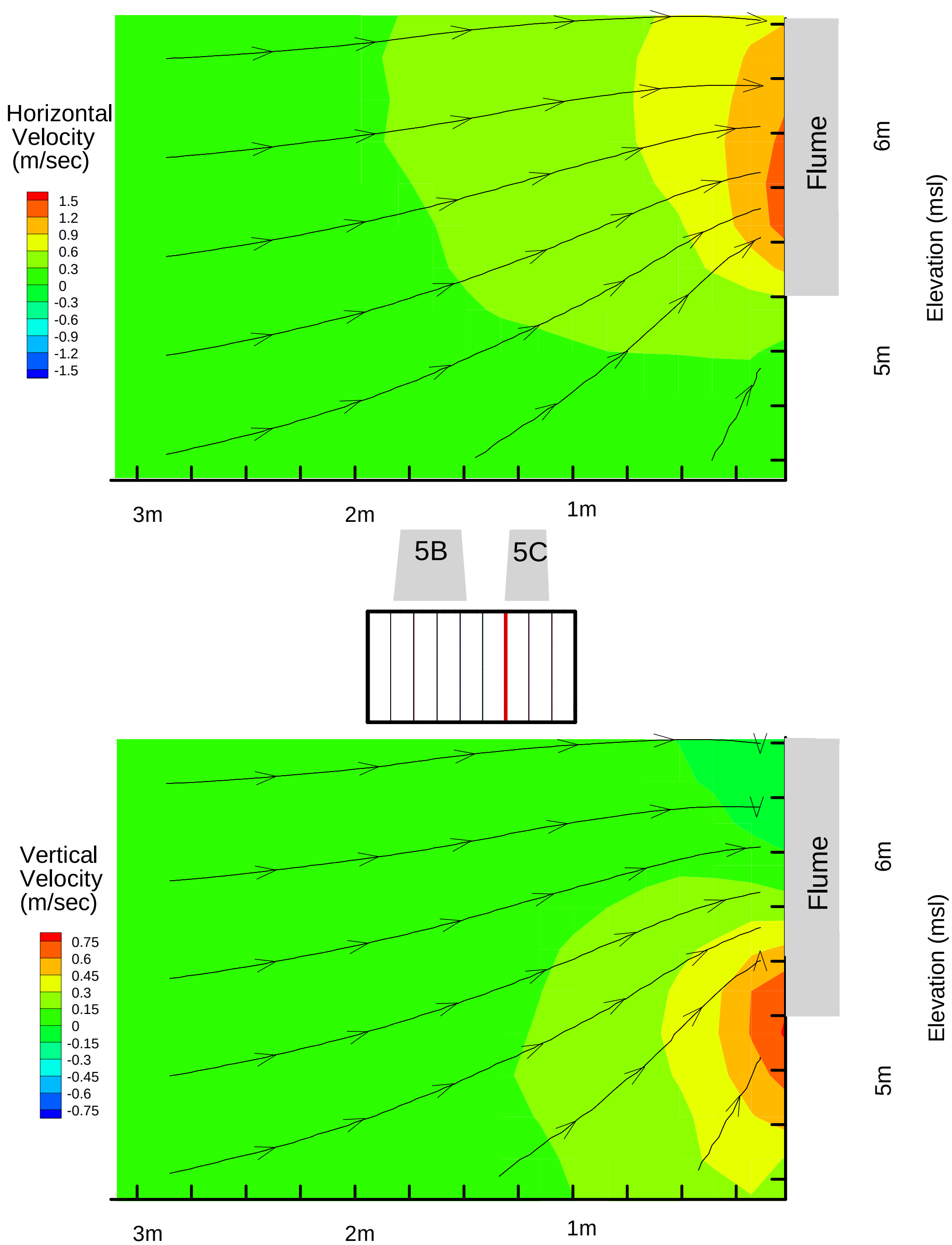

Figure 42. Cross-sectional view of flow field near the entrances of flumes 5B and 5C, showing horizontal (top) and vertical flow velocity components. Cross-sectional slice location shown in figure between plots. Flow is from left to right (east to west).

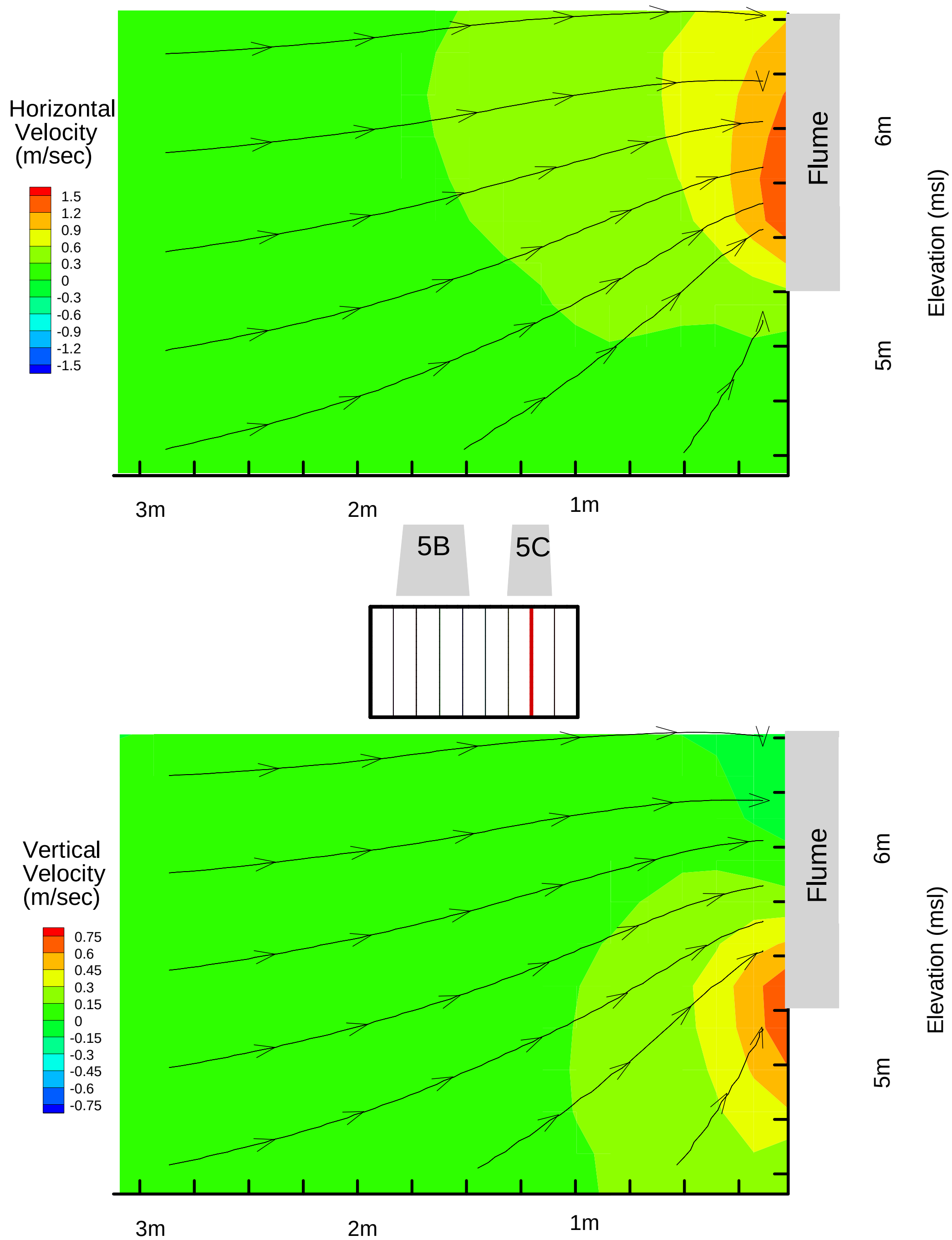

Figure 43. Cross-sectional view of flow field near the entrances of flumes 5B and 5C, showing horizontal (top) and vertical flow velocity components. Cross-sectional slice location shown in figure between plots. Flow is from left to right (east to west).

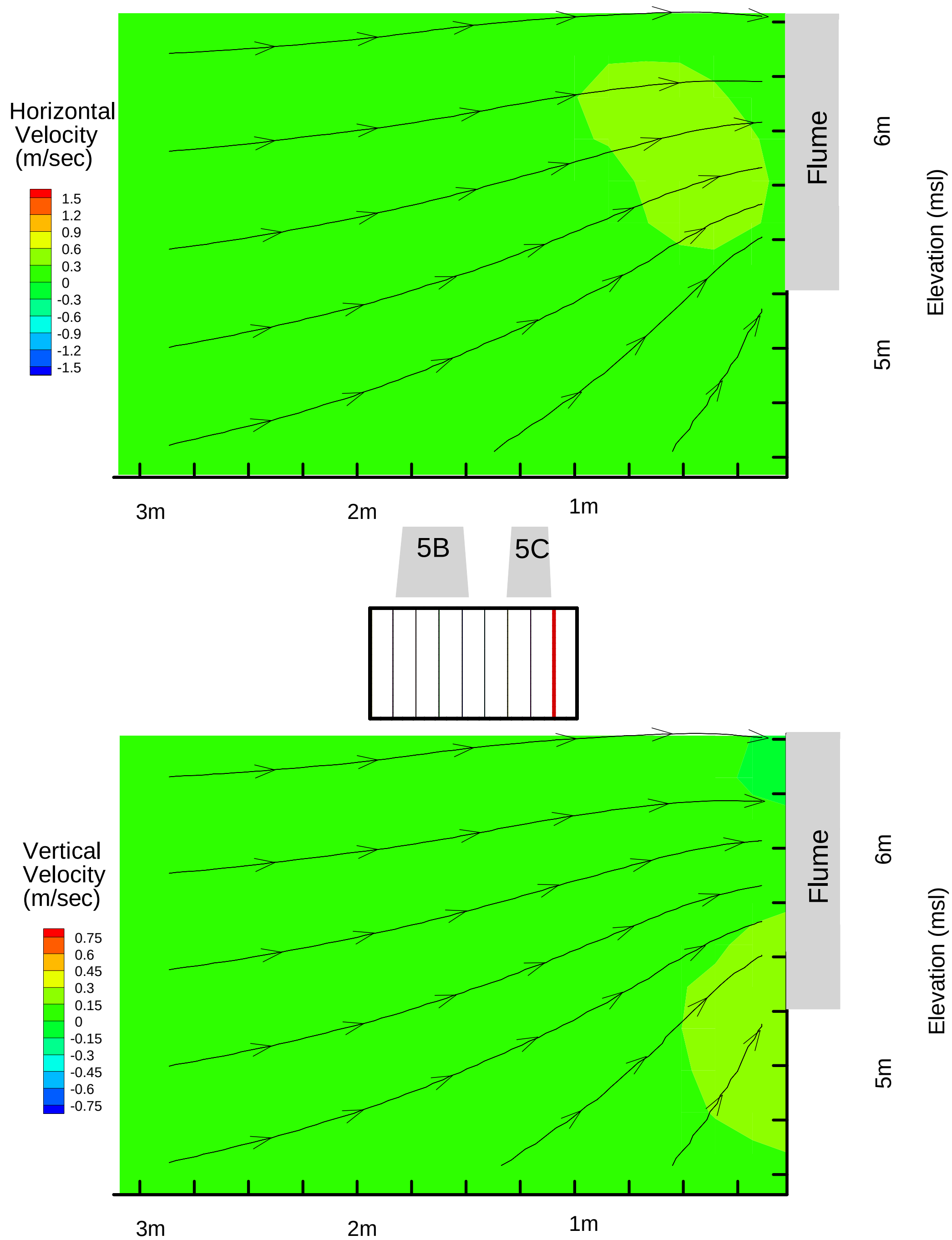

Figure 44. Cross-sectional view of flow field near the entrances of flumes 5B and 5C, showing horizontal (top) and vertical flow velocity components. Cross-sectional slice location shown in figure between plots. Flow is from left to right (east to west).

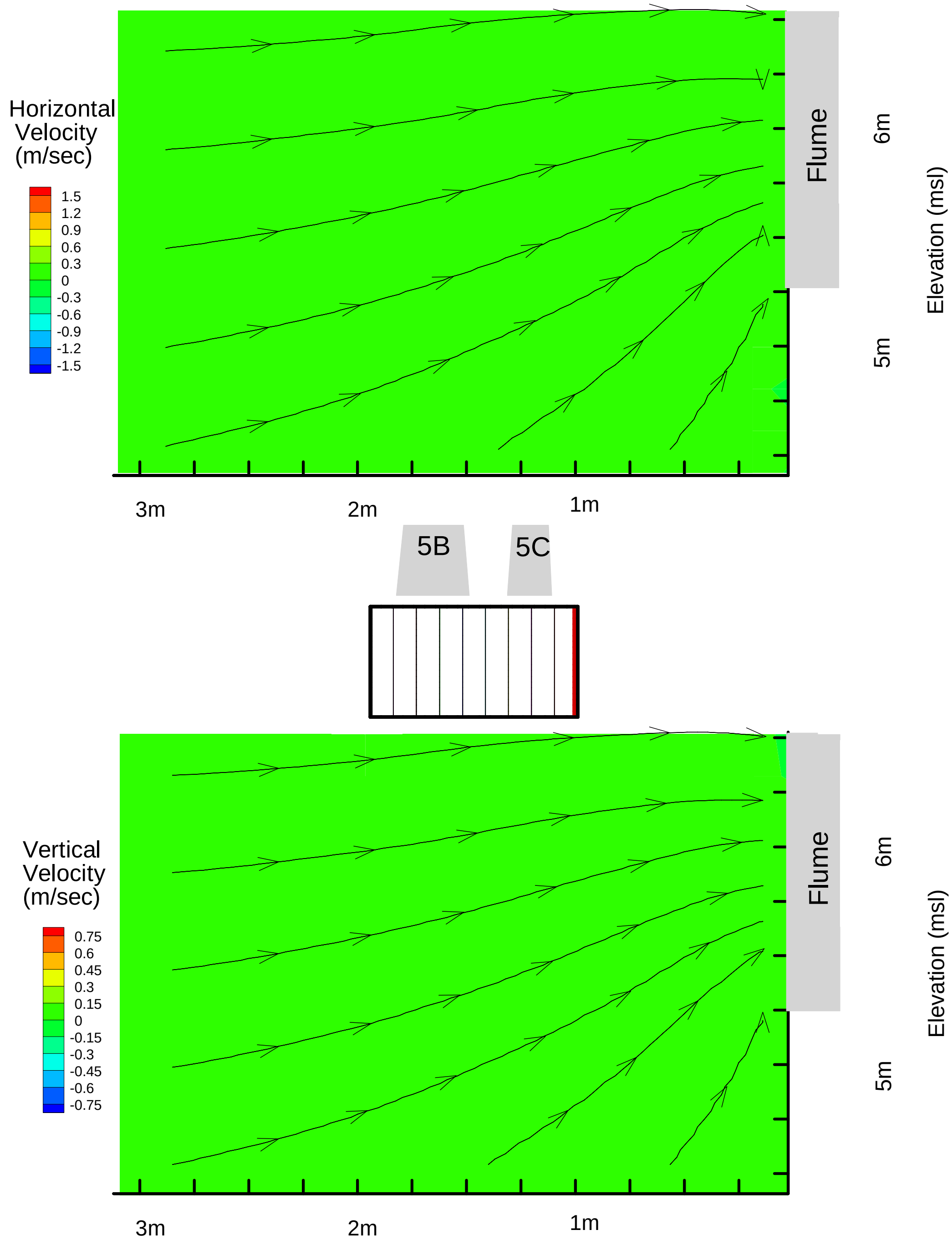

Figure 45. Cross-sectional view of flow field near the entrances of flumes 5B and 5C, showing horizontal (top) and vertical flow velocity components. Cross-sectional slice location shown in figure between plots. Flow is from left to right (east to west).

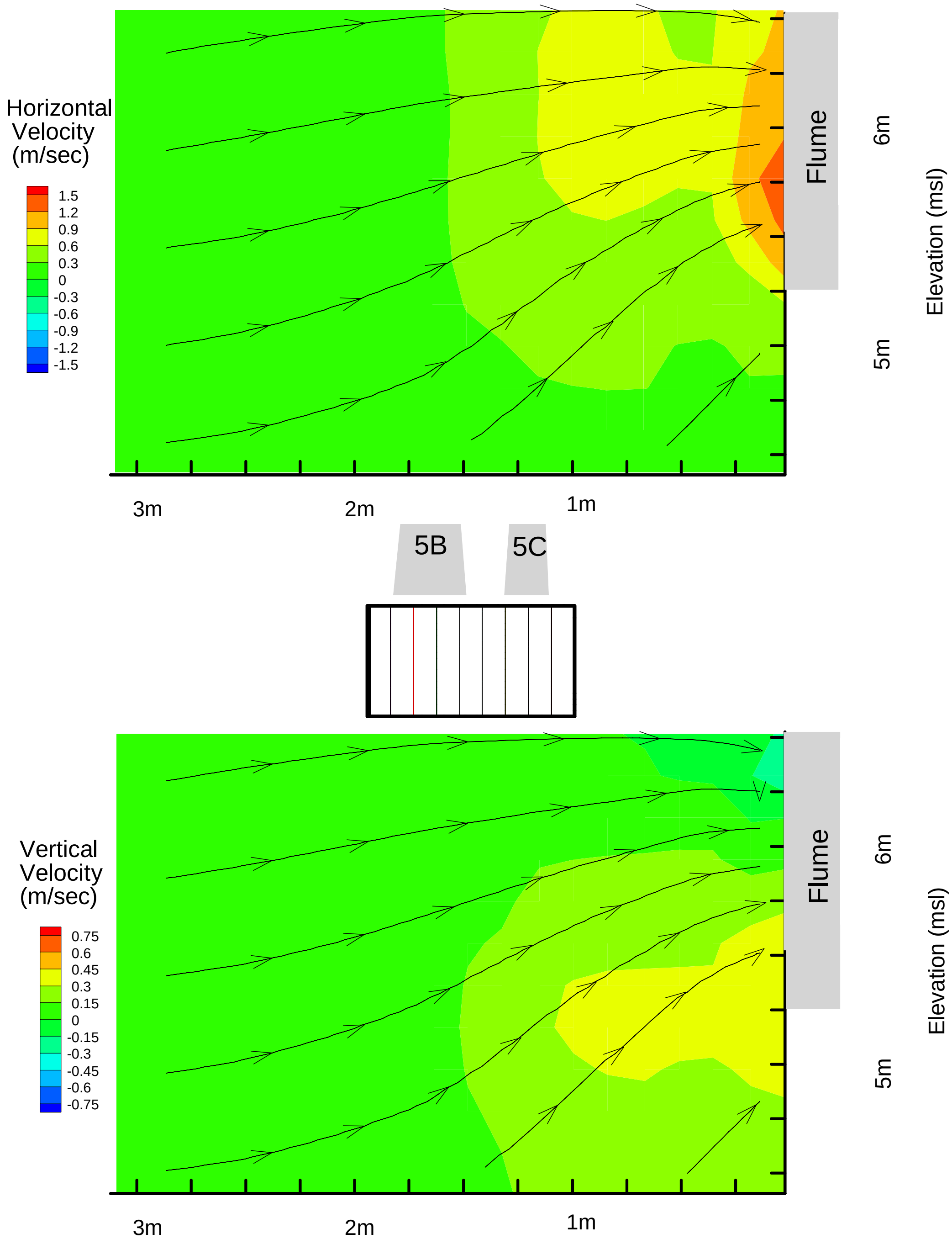

Figure 46. Cross-sectional view of flow field near the entrances of flumes 5B and 5C, showing horizontal (top) and vertical flow velocity components. Cross-sectional slice location shown in figure between plots. These data reflect conditions with log-boom in place. Flow is from left to right (east to west).

Current Profiler

All presented results from current profiler sampling reflect the average total velocity conditions among three depth strata: 0.5 m, 1.0 m, and 1.5 m below the water surface. As expected during baseline conditions (no flumes operating, saltwater return closed), the sampled area showed very little flow (Figure 47). Estimates of current velocity patterns in the spillway forebay were essentially identical when comparing the influence of opening Flume 5B versus the influence of opening flumes 4A, 5B, and 5C one hour after opening the flumes (Figure 48). Generally, velocities of between 0.1 and 0.2 m/s during both conditions characterized the entire sampling area, which does not differ much with what we estimated during baseline conditions (compare Figures 47 and 48). Similarly, we observed no discernible changes in current velocities from the temporal sampling we conducted for either the 1-flume or 3-flume treatment, or with the opening of the saltwater return (Appendix B). The few areas representing higher relative water velocities were likely the result of wakes from boats passing through the sample area.

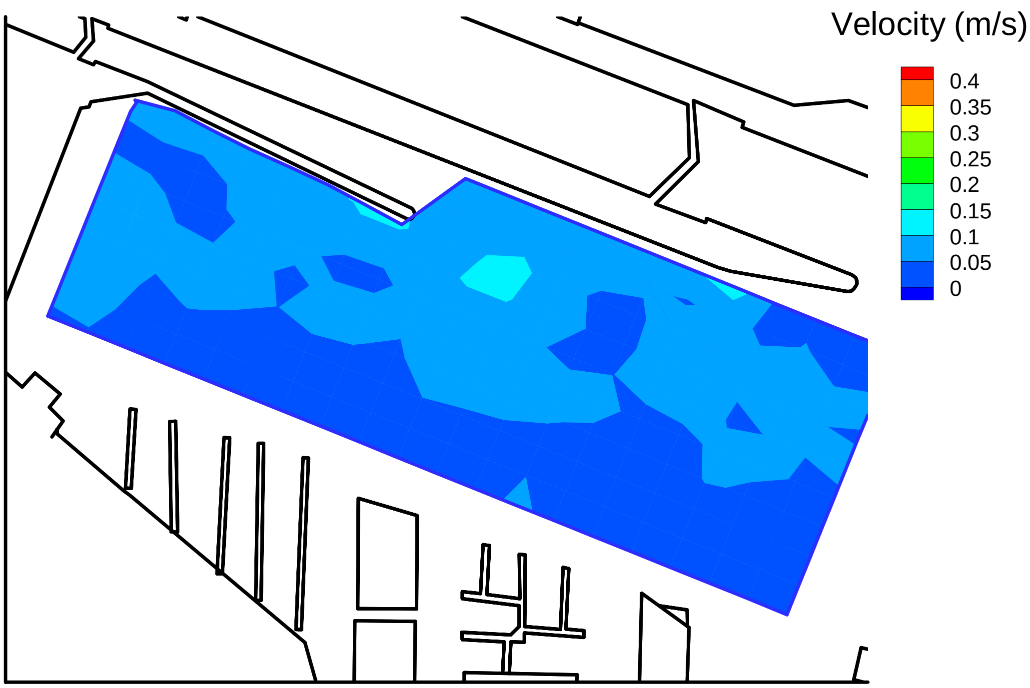

Figure 47. Current velocity patterns in the spillway forebay during baseline flow conditions. Flow through the Project is from right to left.

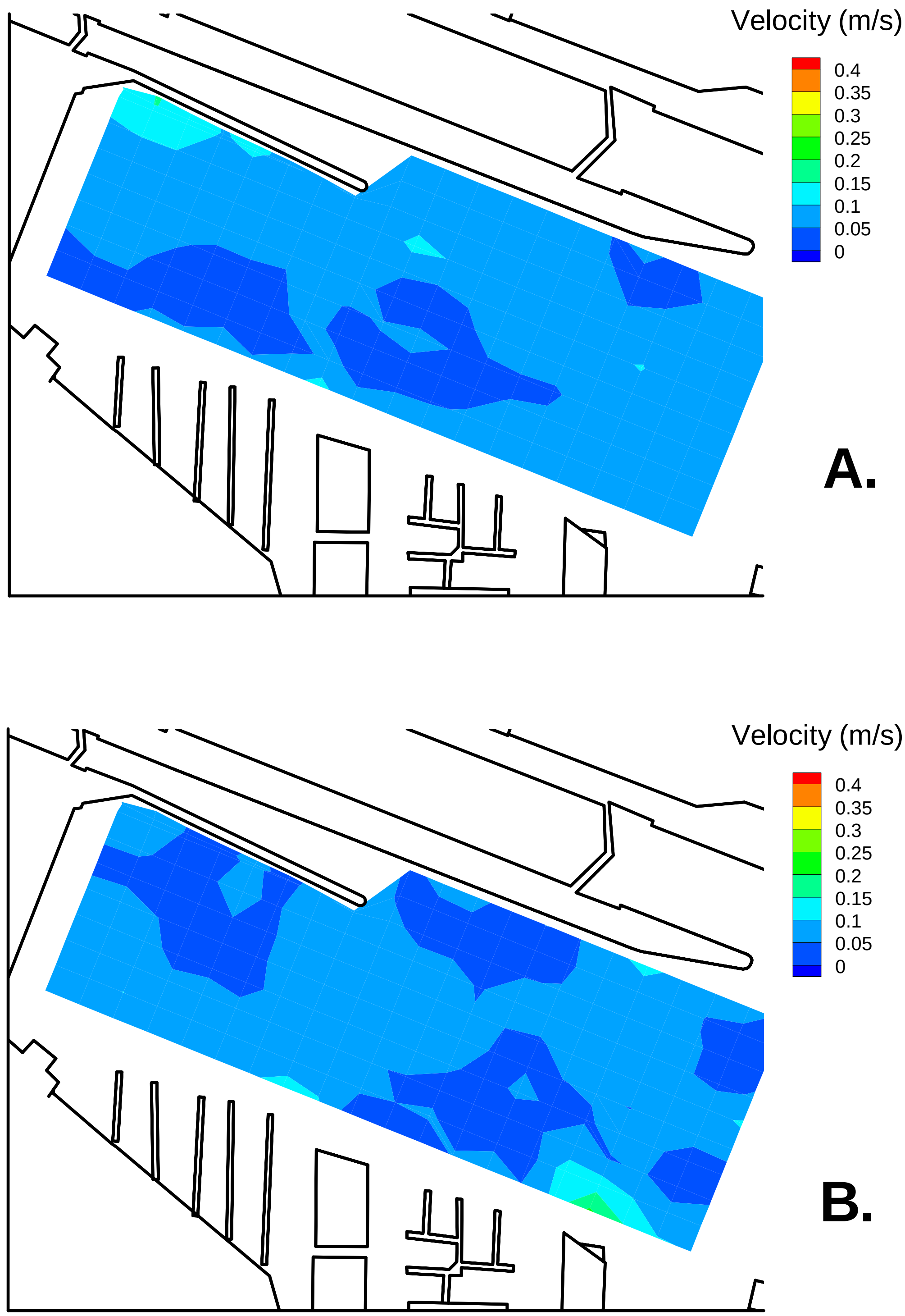

Figure 48. Current velocity patterns in the spillway forebay one hour after opening A) flumes 4A, 5B, and 5C; and B) Flume 5B. The saltwater return was closed, and flow is from right to left.

Diffuser Well Video Surveys

We observed no juvenile or adult salmonids, or fish of any kind in the diffuser well while sampling with the underwater camera system.

Leakage at the Miter Gates

We did not detect any discernible leaks near the seams of the miter gates at the juncture with the lock walls or where the gates come together at the center of the entranceway.

Discussion and Recommendations

Hydroacoustic Detectability

Improvements in detectability modeling results in hydroacoustic estimates that are quantitative and reliable relative indices of fish passage through structures. Our modeling efforts resulted in consistently high effective beam angles (Figure 16), which ensures that the spatial expansion factors we used were not inappropriately overestimating entrainment through the filling culverts. The high beam angles were likely a function of the relatively slow water velocities (< 0.3 m / sec; Table 1). Given the estimated water velocities, our sampling rate of 10 pings / sec was fast enough to obtain reliable entrainment estimates.

Project Passage (Fish Budget)

The results of our fish passage monitoring efforts at the Locks indicate that the spillway flumes, when they were available, were the primary fish passage routes in 2001. Based on estimated total numbers of fish that were in the flumes or entrained into the large lock, 97.6% passed via the flumes. Limited sampling in the entranceway of the small lock and especially at the small lock filling culverts during fill events indicated that the culverts of the small locks are likely not significant passage routes for migrating juvenile salmon. Similarly, sampling in the diffuser well resulted in no observations of fish trapped in the well, which suggests that the saltwater drain is also an unlikely passage route through the Project for juvenile salmon. Biosonics (2000) used both video and hydroacoustic sampling to evaluate smolt entrainment into the saltwater drain, and also concluded that the drain was likely not a significant passage route.

Sampling all potential passage routes was outside the scope of 2001 research efforts. Although there were a small number of days when spillbays were opened to lower the elevation of Lake Washington, we did not sample spillway passage. Biosonics (2000) reported the spillway to be a significant passage route in 2000, and it is likely that spill in 2001 resulted in large numbers of fish being spilled as well. Assuming the likelihood of large numbers of spilled fish, the relative proportion of fish passing the Project via the spillway increases to an even greater level. Additionally, we did not sample passage into the small or large locks while upstream gates were open, or entrainment into the lock chamber during lower lock fill events. As passage through the locks when gates are open is not considered harmful to the fish, lower lock entrainment becomes the only passage route where critical uncertainties exist. Since sampling lower lock entrainment would be very difficult (see Johnson et al. 2001b), we therefore recommend limited use of the lower lock during the juvenile fish passage season.

Effects of Operations on Fish Passage

Passage of fish through the different routes at the Locks is a function of project operations. Fish can only be entrained when fill events occur, and although not evident in this study, the level of entrainment can be minimized by slowing down the rate at which the valves are opened. As observed in this study, and in 2000 (Johnson et al. 2001b), the volume of water spilled over the flumes directly relates to the proportion of fish entrained relative to the proportion of fish passed via the flumes (Figure 31). Combining data from 2000 and 2001, it becomes clear that the greater the volume of water passed over the flumes, the greater the proportion of flume-passed fish relative to culvert-entrained fish (Figure 49). Summarizing these same data into bins of 130 cfs (3.68 cms) each indicates that > 130 cfs is necessary to achieve > 50% flume passage, and in order to achieve > 92% flume passage, it would entail > 260 cfs (7.36 cms) of flow over the flumes (Figure 50). However, the 95% confidence limits overlap between the two larger bin sizes, so there is no significant difference between the estimates of relative flume passage at those spill volumes. Given a full lake, operation of three or more flumes would be required to pass more than 260 cfs.

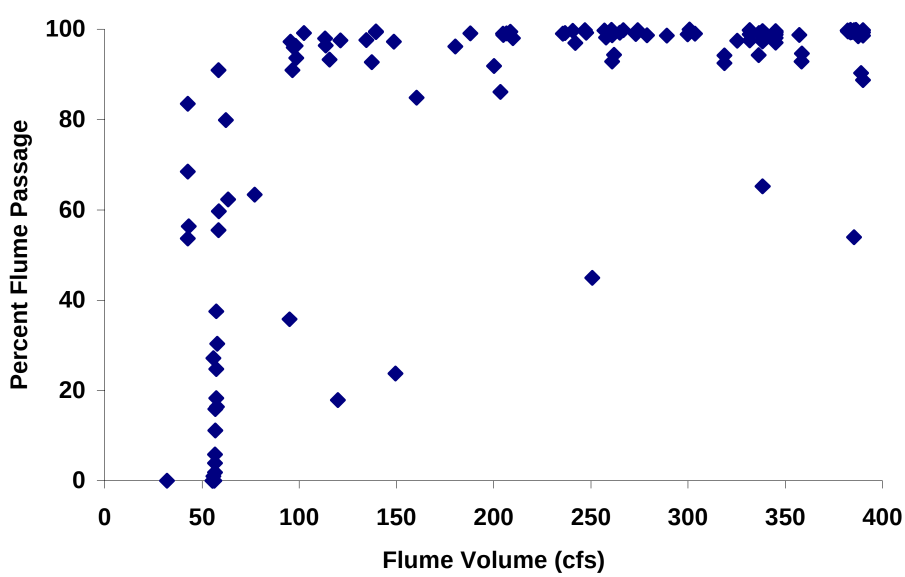

Figure 49. Percent flume passage (relative to culvert entrainment) and flume volume for years 2000 and 2001 combined.

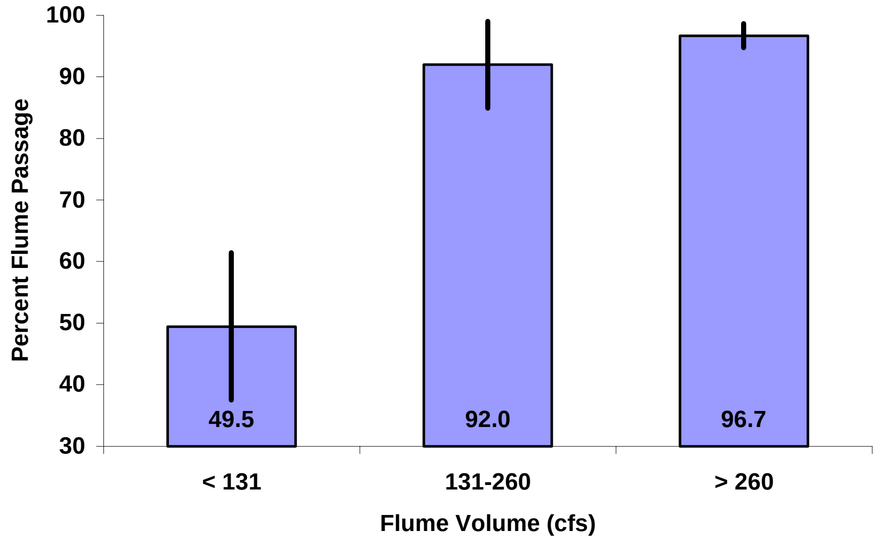

Figure 50. Percent flume passage (relative to culvert entrainment) and flume volume in 130 cfs bins for years 2000 and 2001 combined. The mean by flume volume bin is shown at the base of the bars and the error bars represent 95% confidence intervals.

In order to gain insight into the relationship between flume volume discharge (operations) and fish passage, it is essential to have an accurate and reliable means to acquire operations data. Flume closures were the result of many circumstances including poor performance of PIT tag readers, periodic cleaning of flumes due to excessive buildup of milfoil, safety precautions associated with performing other work in the vicinity of the outfalls, research tasks requiring specific flume operations, and human error (not opening or closing flumes at designated times). We noted flume operations data on a daily basis when we were present at the Project, and relied on log sheets filled out and provided to us by the lockmasters for operations information during non-business hours and for days we were not present. Unfortunately, we found numerous errors in the log sheets regarding flume operations (e.g., in one instance the logs indicated the flumes were open all day when in fact they were closed all day). Since the Water Management Group obtains flume volume data exclusively from the lock log sheets to develop water budgets and other volume related projections and reports, it is critical that flume volume information they receive is also reliable and accurate. To remedy this problem both for the sake of fish passage investigation issues and water budgeting concerns, we recommend the use of sensor switches mounted to the flume openings and connected to data loggers. This simple, low-cost solution will provide for the acquisition of accurate and reliable flume operation data.

Our analysis of fish passage at the flumes as a function of flume volume indicates that Flume 4A generally passed more fish per water volume than all the other flumes on days when all flumes were operational (Figure 29). However, analysis of PIT tag data does not indicate this same result (P. DeVries, R2 Consultants, Pers. Comm.), which suggests that perhaps the visual count sampling technique may be biased. Since considerably less water flows out the outfall of Flume 4A as compared to the other flumes, it is likely that counts are underestimated to a larger degree for the other flumes as compared to Flume 4A. The greater volumes of water pouring out of the other flumes could be obscuring the passing fish from the counters' vision more than at Flume 4A so that Flume 4A would appear to pass more fish per water volume than do the other flumes. We intend to examine this issue further by comparing the count data with the PIT tag data once the report of the PIT tag effort is completed and approved for release. Additionally, if the Washington Department of Fish and Wildlife design and build a new flume outfall sampler in 2002 as planned, we will test for biases in our visual sampling by comparing visual counts to outfall sampler counts on a flume-specific basis. The results from this comparison will also allow for the calculation of multipliers that we can apply to our counts to get more accurate estimates of actual numbers of fish passing through the flumes.

Temporal Trends in Fish Passage

The observed primary peak in culvert-entrained fish occurred in late May through the third week in June (Figure 17), a few weeks earlier than the peak in 2000 (Johnson et al. 2001). A secondary peak occurred in mid to late July through early August (Figure 17), which coincides with the limited operation of the spillway flumes and decreased flume volume discharge (Figure 31) due to water conservation measures at that time. The increase in entrainment over time as a result of limited and no-flow conditions at the spillway flumes is also evident in the entrainment estimates in terms of mean number of entrained fish per fill (Figure 18). Late in the season when flume discharge was limited, the mean number of fish entrained per fill increased as compared to earlier in the season, with the exception of the peak period. This same result was observed in 2000 (Johnson et al. 2001b). These trends not only indicate the influence of flume discharge on culvert entrainment, but also highlight the fact that considerable numbers of migrant fish remaining in the system late in the year do not have the option of passing the Project via the flumes and must pass through the navigation locks.

The diel pattern of entrainment showing an increase during nighttime hours was generally similar between full lock and upper lock chamber fills (Figure 22), which contrasts with 2000 data (Johnson et al. 2001b) that showed much higher entrainment at night with full chamber but not upper chamber fills. The very high entrainment estimate for the 0800 hour (Figure 22) is not indicative of a trend but instead is driven by a single fill event on 9 June that entrained an estimated 709 fish. The increased entrainment during nighttime hours observed in 2000 and 2001 conflicts with results from other studies at the Locks that showed lower fish abundances during the day than at night near the culvert entrances (Dillon and Goetz 1999; Johnson et al. 2001a). Additionally, other investigations have shown negligible fish passage over the spillway at night versus day (Goetz et al. 1999; DeVries 2000; DeVries 2002). The reasons for the differences in diel passage patterns through the Project are unclear but we speculate that it may be a function of species-specific behavioral differences. The planned application at the Locks of a newly-designed ultrasonic tag system for tracking individual juvenile salmon will likely aid in answering this question.

Differences in Entrainment Between Upper and Full Locks

As in the previous passage season (Johnson et al. 2001b), full chamber fill events entrained greater numbers of fish than did upper chamber fills (Figure 19). Since almost twice the amount of water is required to fill the full lock as opposed to the upper lock alone, it is reasonable to expect that full lockages would entrain more fish than would upper chamber lockages. Additionally, the area of influence where fish are at risk of being entrained during fill events is likely larger and extends up farther into the Lake Washington Ship Canal during full lockages than during upper fill events. As upper chamber fill events result in fewer entrained fish than full chamber fills, an obvious and simple strategy for reducing entrainment would be to limit the use of the full lock chamber during the juvenile out-migration season.

Target Strength

Target strength analysis is an important element of hydroacoustic-based fish passage investigations since detectability modeling requires an estimate of mean target strength, and fish lengths can be approximated based on mean target strengths using regression techniques (Love 1971, 1977). Target strength distribution analysis of entrained and non-entrained fish through the study period showed that smaller fish were entrained to a greater extent than larger fish (Figure 23), a result we also observed in 2000 (Johnson et al. 2001b). This result suggests that larger fish with greater swimming speed and stamina can avoid entraining flows more readily than can smaller fish. An analysis of the time history of target strength distribution (Figure 24) suggests that each species and or population of migrants are size variable, and that larger fish within each migrant group are avoiding entrainment.

Vertical Distribution

Examination of the vertical distributions of fish in the area near to the culvert entrances is important, especially during periods prior to fill events, because the position of the fish relative to the entrances can be used to predict the potential for entrainment. If fish are distributed at depths greater than or equal to 6.5 meters from the surface (1 m above the culvert entrance ceiling to the culvert floor), they are “at risk” of being entrained. Daytime vertical distributions of fish during fill events observed in 2001 (Figure 25) were similar to patterns observed in 1998 (Johnson et al. 2001a) and in 2000 (Johnson et al. 2001b). However, the vertical distribution during the day prior to fill events was not skewed towards the floor like in past years and at night in 2000 (Johnson et al. 2001) and 2001, but instead was skewed towards the surface. The explanation for this apparent change in vertical distribution from past years is unknown. Regardless of this result, we still consider culvert entrainment of juvenile salmon a serious concern, and we advocate continued use and testing of behavioral technologies such as strobe lights and turbulence induction systems to minimize entrainment and increase spillway passage through the Project. Johnson et al. (2001a) demonstrated the efficacy of strobe lights for redistributing fish and reducing entrainment in a pilot study at the Locks in 1998, and we are planning further larger-scale strobe light evaluations at the Locks in 2002.

Flow Characterization and Fish Behavior at Entrance to Flume 5B

Normal operation of the spillway flumes entails the placement of a V-shaped log boom in the spillway forebay to prevent floating debris from entering and clogging the flumes. The log boom certainly affects the flow field near the flume entrances, and we acquired data with the boom in place in an attempt to determine its influence on the flow field (Figure 46). However, the boom itself prevented us from sampling the entire area of interest to us because it was where we needed to position the boat for data collection, and we could not sample by positioning the boat inside the boom since this would then confound whatever effects the boom had on the flow field. We realize the limitations of the comparison of boom to without-boom conditions and do not try to analyze and develop this comparison. Note then that the discussion below is based on flow data collected without the boom in place and fish behavioral data acquired with the boom in place.

The results of our sampling of the current velocity fields in front of the entrances to flumes 5B and 5C without the log boom in place has yielded a three-dimensional picture of that flow field (Figures 32 – 45) and can potentially provide insights explaining some of the fish behavior observed with video sampling at the entrance to Flume 5B. The tail-first orientation we observed for the great majority of fish passing into the flume in high flows near the entrance concurs with observations made by other investigators. Migrating sockeye smolts orient head downstream when flow is uniform and quiet, but turn and orient tail downstream when water flows accelerate and become turbulent (Hartman et al. 1967; Foerster 1968). Coho smolts turn tail first as they approach falls or rapids, and some have been observed to turn and head downstream head first as they pass over the falls (Sandercock 1991), a behavior we have observed while counting fish in the flume outfalls. Video sampling results indicated that tail-first fish entered the camera's field-of-view at rates slower than the current velocities, which suggests that the fish were not simply entrained in those high velocities but instead were easing their way into the flume opening. This contrasts with the few individuals observed oriented headfirst that seemed to pass into the camera's field-of-view and then into the flume entrance at about the same rate as the current velocity (estimated to be 1 m/s). We speculate that these individuals observed to be "going with the flow" were likely diseased or injured, which would explain this potentially aberrant behavior.

One of the more interesting observations gleaned from the video sampling was that groups or portions of fish groups that did not enter the flume typically avoided the flume entrance by either swimming laterally towards the north or swimming down below the entrance. The results of the current velocity sampling indicated a pocket of stagnant and upstream moving water near the bottom and towards the north side of the entrance to Flume 5B at elevation 5.6 m (Figure 33, bottom plot). Potentially this area of counter-flow could explain the diversion of some fish away from the flume entrance. Fish may encounter those counter flows and become confused about which direction to swim, which could result in a delay in passage. We recommend further investigation into the influence of the counter flows in order to determine if the flume design can be modified to curtail those flows and thus minimize delays in passage.

Effect of timing and volume of flume operation on upstream current profiles

The primary objective of the current profiler sampling was to determine how long it takes flow patterns in the spillway forebay to set up after opening one flume (5B) and three flumes (4A, 5B, and 5C). Our results (Figures 47, 48, Appendix B) were surprising to us given that they showed little change in flow patterns when comparing baseline conditions to initial sampling runs (one hour after flumes were opened) or comparing flow patterns between like runs of different flume opening treatments. The few apparent differences in flow patterns among the current profile contour plots are likely attributable to wakes produced by recreational boats having passed through the sampling area (see Appendix B). We assumed that flow patterns would set up in less than an hour, but since the patterns were essentially the same for baseline and each hourly sampling period, we could not test our assumption. We speculate that the influence of the flume operations on upstream flow patterns that we tested is too small to detect with current profile sampling. In the previous season, we observed with a current profiler the higher velocity zones immediately upstream of the flume entrances when comparing one flume to three flume-operating conditions (Johnson et al. 2001b). However, in 2000 the three-flume treatment consisted of flumes 4B, 5B, and 5C, whereas in 2001, the treatment was based on operating flumes 4A, 5B, and 5C. This amounts to a decrease of almost 25% in flume volume from 2000 to 2001, which may explain why we did not observe flow pattern differences between the two flume treatments.

Conclusions

The results of our 2001 fish passage investigations have allowed for further verification of the effectiveness of restoration measures recently undertaken at the Locks. The efficacy of the spillway flumes for passing large numbers of juvenile salmonids, and thus reducing culvert entrainment, was clearly demonstrated based on relative passage estimates between the two routes. As long as enough water was available to pass at least 260 cfs (7.36 cms), culvert entrainment was limited to less than 4% of total estimated project passage. By combining the effectiveness of the flumes for passing fish with the use of strobe lights to repel fish from the area influenced during fill events, the proportion of fish entrainment would likely decrease to levels lower than estimated in 2001. If the strobe lights prove to be as effective as reported in a pilot study conducted at the Locks in 1998 (mean fish densities at the depth of the culvert during fill events decreased by 87% during strobe light-on treatments as compared to control treatments; Johnson et al. 2001a), then during periods when enough water is available for flume operation, less than 1% of the outmigrants will be at risk of entrainment.

Additional research is necessary to verify the combination effect of using strobe lights and spillway flumes for reducing fish entrainment into the large lock filling culverts. If the strobe light system proves to be reliable, we will initiate effectiveness testing in April of 2002. Another primary objective in 2002 will be to determine the accuracy of our visual sampling for flume passage estimation on a flume-specific basis. If the flume outfall sampler is redesigned and rebuilt by the WDFW as planned, we will then have an opportunity to calibrate our flume counts for each individual flume. More accurate estimates of fish passage will then result in better estimates of fish passage per water volume. This information would then directly tie water conservation decisions to predictable fish passage results (i.e., how will fish passage at the Locks be affected by variable flume operation scenarios).

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Appendix A. List of sampled fill events during the study period at Hiram M. Chittenden Locks in 2001. Lock chambers filled were either full (F) or upper (U). Valve procedures (fill types) used were either “graduated” (G) or “intermediate” (I). Fills without listed end times were not processed due to excessive noise associated with raising the saltwater barrier.

Date	Start Time	End Time	Chamber	Fill Type	Date	Start Time	End Time	Chamber	Fill Type
24-Apr	1319	1333	U	I	6-May	1350		F	I
24-Apr	1356	1410	U	I	6-May	1546		F	I
25-Apr	0256	0309	F	I	6-May	1820		U	I
25-Apr	1026	1039	U	I	6-May	1927		U	I
25-Apr	1754	1804	U	I	6-May	2143		U	I
25-Apr	1844	1853	U	I	6-May	2226		U	I
25-Apr	2031	2040	U	I	7-May	0527	0536	U	I
26-Apr	0234	0245	U	I	7-May	1136	1158	F	I
26-Apr	0630	0639	U	I	7-May	1350		F	I
26-Apr	1755	1806	U	I	7-May	1608		U	I
26-Apr	2113	2122	U	I	7-May	1934	1943	U	I
27-Apr	0324	0335	U	I	7-May	2310		U	I
27-Apr	0935		U	I	8-May	0648		U	I
27-Apr	1812	1826	F	I	8-May	0806		U	I
28-Apr	1234	1247	U	I	8-May	1404	1425	F	I
28-Apr	1732	1745	U	I	8-May	1531	1548	F	I
28-Apr	1803	1815	U	I	8-May	1749	1759	U	I
29-Apr	1044	1056	F	I	8-May	2155	2205	U	I
29-Apr	1208	1223	F	I	9-May	0205	0216	U	I
29-Apr	1423	1437	U	I	9-May	0302	0313	U	I
30-Apr	0714	0724	U	I	9-May	1140		U	I
1-May	1228	1240	F	I	9-May	1317		U	I
2-May	0508	0518	U	I	9-May	1549		F	I
2-May	0648	0700	U	I	9-May	1751	1801	U	I
2-May	0739	0751	U	I	9-May	1918	1927	U	I
2-May	0919	0935	F	I	9-May	2012	2021	U	I
2-May	1900		F	I	10-May	0915	0926	U	I
2-May	2037		F	I	10-May	1008	1020	U	I
3-May	0845	0857	U	I	10-May	1300		U	I
3-May	0930	0942	U	I	10-May	1430		U	I
3-May	1105	1122	F	I	10-May	1555	1608	U	I
3-May	1355	1411	F	I	10-May	1756	1807	U	I
3-May	1612	1625	F	I	10-May	2239	2248	U	I
4-May	0955	1008	U	I	11-May	0134	0145	U	I
4-May	1150		F	I	11-May	0250		U	I
4-May	1856	1911	F	I	11-May	1159	1217	F	I
5-May	0150	0200	F	I	11-May	1349	1404	U	I
5-May	0503	0512	U	I	11-May	1526	1540	U	I
5-May	0858		U	I	11-May	1647	1700	U	I
5-May	1336	1348	U	I	11-May	1831	1842	U	I
5-May	1524	1534	U	I	11-May	2018	2027	U	I
5-May	1649		U	I	12-May	0137	0147	U	I
5-May	1802	1812	U	I	12-May	0932	0942	U	I
5-May	2238		U	I	12-May	1135	1147	U	I
6-May	0255	0304	U	I	12-May	1410	1424	U	I
6-May	0355	0404	U	I	12-May	1554	1608	U	I
6-May	0802	0818	F	I	12-May	1754	1811	F	I
6-May	0940		F	I	12-May	1923	1934	U	I
6-May	1147	1209	F	I	12-May	2342	2351	U	I

Appendix A. (cont.).

Date	Start Time	End Time	Chamber	Fill Type	Date	Start Time	End Time	Chamber	Fill Type
13-May	0738	0748	U	I	19-May	1018	1031	U	I
13-May	0857	0907	U	I	19-May	1210	1222	U	I
13-May	1053	1104	U	I	19-May	1347	1358	U	I
13-May	1334	1353	F	I	19-May	1542	1552	U	I
13-May	1517	1531	U	I	20-May	0706	0718	U	I
13-May	1651	1705	U	I	20-May	0815	0828	U	I
14-May	1018	1031	F	I	20-May	1135	1148	U	I
14-May	1204	1218	F	I	20-May	1407	1418	U	I
14-May	1617	1630	U	I	20-May	1602	1613	F	I
14-May	1715		U	I	20-May	1726	1736	U	I
14-May	1757		U	I	20-May	1841	1851	U	I
15-May	0049	0058	U	I	20-May	1929	1942	F	I
15-May	1014	1025	U	I	20-May	2110	2122	U	I
15-May	1159	1210	U	I	21-May	0613	0623	U	I
15-May	1257		U	I	21-May	0810	0823	U	I
15-May	1528	1540	U	I	21-May	0910	0924	U	I
15-May	1630		F	I	21-May	1104	1119	U	I
15-May	1950	2002	U	I	21-May	1313	1326	U	I
16-May	0121	0130	U	I	21-May	1455	1506	U	I
16-May	0545		U	I	21-May	1801	1810	U	I
16-May	0645		U	I	21-May	1915	1925	U	I
16-May	0841	0852	U	I	22-May	0151	0202	U	I
16-May	1309	1320	U	I	22-May	1035	1050	U	I
16-May	1434	1445	U	I	22-May	1223	1237	U	I
16-May	1558	1610	U	I	22-May	1409	1421	U	I
16-May	1710	1720	U	G	22-May	1552	1602	U	I
16-May	1825	1838	U	I	22-May	1821	1830	U	I
16-May	1926	1939	U	I	23-May	0001	0012	U	I
16-May	2112	2128	F	I	23-May	0445	0454	U	I
17-May	0252	0301	U	I	23-May	0512	0521	U	I
17-May	0642	0653	U	I	23-May	0719	0729	U	I
17-May	0720	0731	U	I	23-May	1101	1118	U	G
17-May	1037		U	I	23-May	1242	1257	U	I
17-May	1113	1125	U	I	23-May	1352	1406	U	I
17-May	1414	1425	U	I	23-May	1607	1620	F	I
17-May	1802	1814	U	I	23-May	1727	1737	F	I
17-May	1908	1918	U	G	23-May	1811	1820	U	I
17-May	2013	2025	U	I	23-May	2030	2039	U	I
17-May	2209	2224	F	I	24-May	0001	0012	U	I
18-May	0612	0625	F	I	24-May	0131	0142	U	I
18-May	0946	0959	U	I	24-May	0932	0944	U	I
18-May	1029	1042	U	I	24-May	1119	1136	U	G
18-May	1149	1201	U	I	24-May	1230	1245	U	I
18-May	1541	1552	U	I	24-May	1337	1353	U	G
18-May	1641	1652	U	I	24-May	1630	1641	U	I
18-May	1716	1727	U	I	24-May	1811	1820	U	I
18-May	1756	1807	U	I	24-May	2055	2104	U	I
18-May	1840	1856	F	I	25-May	0244	0254	U	I
18-May	2014	2026	U	I	25-May	0857	0908	U	I
19-May	0049	0101	F	I	25-May	1049	1109	F	I

Appendix A. (cont.).

Date	Start Time	End Time	Chamber	Fill Type	Date	Start Time	End Time	Chamber	Fill Type
25-May	1249	1305	U	I	1-Jun	0500	0510	U	I
25-May	1444	1507	F	I	1-Jun	0833	0846	U	I
25-May	1637	1653	F	I	1-Jun	1059	1111	U	I
25-May	1737	1750	F	I	1-Jun	2123	2135	U	I
25-May	2329	2338	U	I	1-Jun	2241	2255	F	I
26-May	0745	0754	U	I	2-Jun	0106	0115	U	I
26-May	0855	0905	U	I	2-Jun	0509	0520	U	I
26-May	1100	1113	U	I	2-Jun	0822	0836	U	I
26-May	1252	1316	F	I	2-Jun	0953	1007	U	I
27-May	1254	1308	U	I	2-Jun	1102	1115	U	I
27-May	1549	1604	U	I	2-Jun	1207	1219	U	I
27-May	1827	1843	F	I	2-Jun	1320	1333	F	I
27-May	2229	2237	U	I	2-Jun	1547	1557	U	I
27-May	2332	2340	U	I	2-Jun	1618	1628	U	I
28-May	0801	0811	U	I	2-Jun	1752	1802	U	I
28-May	0855	0905	U	I	3-Jun	0730	0743	U	I
28-May	1101	1114	F	I	3-Jun	1328	1339	U	I
28-May	1331	1350	F	I	3-Jun	1615	1625	U	I
28-May	1605	1628	F	I	3-Jun	1721	1731	U	I
28-May	1835	1852	F	I	3-Jun	1911	1923	F	I
29-May	0224	0235	F	I	3-Jun	2022	2033	U	I
29-May	0624	0635	U	I	3-Jun	2127	2138	U	I
29-May	0744	0755	U	I	4-Jun	0152	0201	U	I
29-May	0905	0916	U	I	4-Jun	0541	0551	U	I
29-May	1127	1140	F	I	4-Jun	0904	0918	U	I
29-May	1618	1632	U	I	4-Jun	1706	1715	U	I
29-May	1813	1833	F	I	5-Jun	0046	0057	U	I
29-May	1911	1924	U	I	5-Jun	0552	0601	U	I
29-May	2230	2240	F	I	5-Jun	1504	1518	F	I
30-May	0214	0223	U	I	5-Jun	1832	1841	U	I
30-May	0303	0312	F	I	5-Jun	2018	2027	U	I
30-May	0638	0650	U	I	5-Jun	2215	2225	U	I
30-May	1227	1238	U	I	6-Jun	0457	0506	U	I
30-May	1319	1330	U	I	6-Jun	0744	0758	F	I
30-May	1618	1631	U	I	6-Jun	0906	0919	U	I
30-May	1728	1742	U	G	6-Jun	1159	1214	U	I
30-May	1829	1843	U	G	6-Jun	1439	1452	U	I
30-May	1950	2003	U	I	6-Jun	1604	1618	F	I
30-May	2142	2153	U	I	6-Jun	1738	1748	F	I
30-May	2323	2332	U	I	6-Jun	2051	2100	U	I
31-May	0421	0431	U	I	7-Jun	0439	0448	U	I
31-May	0552	0604	U	I	7-Jun	0630	0639	U	I
31-May	0945	0957	U	I	7-Jun	0733	0744	U	I
31-May	1133	1144	U	I	7-Jun	0844	0856	U	I
31-May	1326	1337	U	I	7-Jun	1109	1125	U	G
31-May	1818	1829	U	G	7-Jun	1235	1250	U	I
31-May	1935	1948	U	I	7-Jun	1359	1415	U	G
31-May	2102	2114	U	I	7-Jun	1625	1639	F	I
31-May	2158	2209	U	I	7-Jun	1754	1804	U	I
1-Jun	0208	0216	U	I	7-Jun	2249	2259	F	I

Appendix A. (cont.)

Date	Start Time	End Time	Chamber	Fill Type	Date	Start Time	End Time	Chamber	Fill Type
7-Jun	2356	0006	U	I	14-Jun	0641	0653	U	I
8-Jun	0938	0955	F	I	14-Jun	0813	0825	U	I
8-Jun	1145	1200	U	I	14-Jun	1021	1032	U	I
8-Jun	1312	1327	U	I	14-Jun	1300	1314	F	I
8-Jun	1435	1449	U	I	14-Jun	1437	1449	U	I
8-Jun	1615	1632	F	I	14-Jun	1716	1727	U	G
8-Jun	1720	1731	U	I	14-Jun	1812	1824	U	I
8-Jun	1833	1842	U	I	14-Jun	1913	1925	U	I
8-Jun	1904	1913	U	I	14-Jun	2023	2034	U	I
8-Jun	2012	2021	U	I	15-Jun	0043	0052	U	I
8-Jun	2109	2118	U	I	15-Jun	0224	0234	U	I
8-Jun	2258	2307	U	I	15-Jun	0700	0712	U	I
9-Jun	0807	0818	F	I	15-Jun	0745	0758	U	I
9-Jun	0923	0934	U	I	15-Jun	1329	1342	F	I
9-Jun	1151	1205	U	I	15-Jun	1444	1457	F	I
9-Jun	1355	1410	U	I	15-Jun	1625	1636	U	I
10-Jun	0500	0511	U	I	15-Jun	1818	1830	U	I
10-Jun	1108	1120	U	I	16-Jun	0005	0014	U	I
10-Jun	1240	1301	F	I	16-Jun	0222	0231	U	I
10-Jun	1438	1501	F	I	16-Jun	0549	0601	U	I
10-Jun	1639	1658	F	I	16-Jun	1010	1023	U	I
10-Jun	1842	1853	U	I	16-Jun	1318	1329	U	I
11-Jun	0145	0155	U	I	16-Jun	1434	1444	U	I
11-Jun	0712	0722	U	I	16-Jun	1654	1705	U	I
11-Jun	1137	1149	U	I	16-Jun	2253	2304	U	I
11-Jun	1400	1414	U	I	17-Jun	0306	0315	U	I
11-Jun	1527	1548	F	I	17-Jun	0808	0822	U	I
11-Jun	1803	1815	U	I	17-Jun	0920	0934	U	I
11-Jun	2031	2040	U	I	17-Jun	1007	1020	U	I
12-Jun	0135	0145	U	I	17-Jun	1124	1137	U	I
12-Jun	0705	0716	U	I	17-Jun	1337	1350	F	I
12-Jun	1214	1226	U	I	17-Jun	1537	1549	F	I
12-Jun	1327	1340	U	I	17-Jun	1659	1709	U	I
12-Jun	1521	1535	U	I	17-Jun	1908	1922	F	I
12-Jun	1810	1823	U	I	17-Jun	2218	2229	U	I
13-Jun	0123	0132	F	I	18-Jun	0712	0725	U	I
13-Jun	0606	0618	U	I	18-Jun	0759	0813	U	I
13-Jun	0729	0740	U	I	18-Jun	0915	0930	U	I
13-Jun	0855	0909	F	I	18-Jun	1201	1214	U	I
13-Jun	1008	1019	U	I	18-Jun	1334	1349	F	I
13-Jun	1141	1152	U	I	18-Jun	1543	1553	U	I
13-Jun	1230	1241	U	I	18-Jun	1752	1802	U	I
13-Jun	1415	1427	U	I	18-Jun	1855	1905	U	I
13-Jun	1539	1551	U	G	18-Jun	2030	2041	U	I
13-Jun	1637	1650	U	I	18-Jun	2202	2213	U	I
13-Jun	1724	1737	U	I	19-Jun	0222	0231	U	I
13-Jun	1817	1830	U	I	19-Jun	1005	1020	U	I
13-Jun	2034	2047	F	I	19-Jun	1141	1155	U	I
13-Jun	2157	2207	U	I	19-Jun	1327	1339	U	I
14-Jun	0007	0016	U	I	19-Jun	1512	1522	U	I

Appendix A. (cont.).

Date	Start Time	End Time	Chamber	Fill Type	Date	Start Time	End Time	Chamber	Fill Type
19-Jun	1700	1709	U	I	25-Jun	0833	0842	U	I
19-Jun	1748	1757	U	I	25-Jun	1012	1023	U	I
20-Jun	0355	0404	U	I	25-Jun	1126	1139	U	I
20-Jun	0730	0742	U	I	25-Jun	1317	1332	U	I
20-Jun	0851	0905	U	I	26-Jun	1018	1028	U	I
20-Jun	1005	1023	U	G	26-Jun	1301	1314	U	I
20-Jun	1119	1134	U	I	26-Jun	1606	1620	U	I
20-Jun	1229	1243	U	I	26-Jun	1713	1726	U	I
20-Jun	1341	1354	U	I	26-Jun	1805	1817	U	I
20-Jun	1448	1459	U	I	26-Jun	2000	2010	U	I
20-Jun	1740	1749	U	I	27-Jun	0610	0626	F	I
20-Jun	1814	1823	U	I	27-Jun	1201	1212	U	I
20-Jun	1850	1859	U	I	27-Jun	1332	1344	U	I
20-Jun	2006	2016	F	I	27-Jun	1433	1446	U	I
21-Jun	0102	0112	U	I	27-Jun	1616	1630	U	I
21-Jun	0701	0712	U	I	27-Jun	1737	1750	U	G
21-Jun	1109	1125	U	I	27-Jun	1928	1939	U	I
21-Jun	1528	1539	U	I	27-Jun	2151	2200	U	I
21-Jun	1622	1632	U	I	27-Jun	2353	0001	F	I
21-Jun	1752	1801	U	I	28-Jun	0916	0927	U	I
21-Jun	2030	2039	U	I	28-Jun	1016	1029	F	I
21-Jun	2116	2125	U	I	28-Jun	1310	1321	U	I
22-Jun	0429	0438	U	I	28-Jun	1511	1527	F	I
22-Jun	0521	0530	U	I	28-Jun	1641	1653	U	G
22-Jun	0628	0637	U	I	28-Jun	1731	1744	U	I
22-Jun	0829	0841	U	I	28-Jun	1824	1837	U	I
22-Jun	0917	0930	U	I	28-Jun	2115	2125	U	I
22-Jun	1137	1153	U	I	28-Jun	2221	2230	U	I
22-Jun	1246	1302	U	I	29-Jun	0132	0141	U	I
22-Jun	1421	1442	F	I	29-Jun	0427	0438	U	I
22-Jun	1759	1808	U	I	29-Jun	0732	0745	U	I
22-Jun	1929	1937	U	I	29-Jun	1103	1114	U	I
22-Jun	2003	2011	U	I	29-Jun	1237	1247	U	I
22-Jun	2058	2107	U	I	29-Jun	1528	1539	U	I
22-Jun	2331	2341	U	I	29-Jun	1619	1630	U	I
23-Jun	0543	0552	U	I	29-Jun	1756	1812	F	I
23-Jun	0820	0830	U	I	29-Jun	2009	2025	F	I
23-Jun	1046	1057	U	I	29-Jun	2340	2349	U	I
23-Jun	1210	1226	U	I	30-Jun	1001	1014	U	I
23-Jun	1418	1433	U	I	30-Jun	1111	1127	F	I
23-Jun	2216	2225	U	I	30-Jun	1256	1308	F	I
24-Jun	0159	0210	U	I	30-Jun	1532	1542	U	I
24-Jun	0745	0754	U	I	30-Jun	1733	1744	U	I
24-Jun	0952	1003	U	I	30-Jun	1845	1856	U	I
24-Jun	1420	1436	U	I	30-Jun	2001	2015	F	I
24-Jun	1612	1632	F	I	30-Jun	2147	2158	U	I
24-Jun	1754	1805	U	I	1-Jul	1055	1108	U	I
24-Jun	2331	2340	U	I	1-Jul	1253	1304	U	I
25-Jun	0147	0158	U	I	1-Jul	1448	1458	U	I
25-Jun	0652	0702	F	I	1-Jul	1626	1636	U	I

Appendix A. (cont.).

Date	Start Time	End Time	Chamber	Fill Type	Date	Start Time	End Time	Chamber	Fill Type
1-Jul	1758	1808	U	I	7-Jul	2003	2012	U	I
1-Jul	1926	1939	F	I	8-Jul	0821	0832	U	I
1-Jul	2024	2038	F	I	8-Jul	0918	0929	U	I
2-Jul	0912	0927	U	I	8-Jul	1100	1120	F	I
2-Jul	1123	1144	F	I	8-Jul	1347	1410	F	I
2-Jul	1347	1358	U	I	8-Jul	1606	1624	F	I
2-Jul	1451	1501	U	I	8-Jul	1809	1819	U	I
2-Jul	1715	1724	U	I	9-Jul	0113	0124	U	I
2-Jul	1850	1900	U	I	9-Jul	0332	0343	U	I
2-Jul	2358	0008	U	I	9-Jul	1245	1259	U	I
3-Jul	0633	0645	U	I	9-Jul	1421	1435	U	I
3-Jul	0900	0915	U	I	9-Jul	1609	1622	U	I
3-Jul	1127	1142	U	I	10-Jul	0634	0644	U	I
3-Jul	1215	1229	U	I	10-Jul	0703	0713	U	I
3-Jul	1340	1352	U	I	10-Jul	0755	0805	U	I
3-Jul	1538	1549	F	I	10-Jul	1002	1016	F	I
3-Jul	1749	1758	U	I	10-Jul	1434	1448	U	I
3-Jul	1942	1951	U	I	10-Jul	1648	1701	U	I
4-Jul	0859	0913	U	I	10-Jul	1816	1827	U	I
4-Jul	1113	1128	U	I	10-Jul	2114	2123	U	I
4-Jul	1313	1333	F	I	11-Jul	0505	0516	U	I
4-Jul	1513	1526	F	I	11-Jul	1226	1238	U	I
4-Jul	1639	1648	U	I	11-Jul	1409	1422	U	I
5-Jul	0406	0415	U	I	11-Jul	1536	1550	U	I
5-Jul	0536	0546	F	I	11-Jul	1633	1646	U	I
5-Jul	0909	0929	F	I	11-Jul	1822	1833	U	I
5-Jul	1131	1155	F	I	11-Jul	2226	2235	F	I
5-Jul	1352	1412	F	I	12-Jul	0417	0429	U	I
5-Jul	1600	1613	F	I	12-Jul	0735	0746	U	I
5-Jul	1723	1732	U	I	12-Jul	0846	0857	U	I
5-Jul	1913	1922	U	I	12-Jul	0937	0948	U	I
5-Jul	2014	2023	U	I	12-Jul	1052	1103	U	I
5-Jul	2112	2121	U	I	12-Jul	1331	1343	U	I
6-Jul	0143	0153	U	I	12-Jul	1629	1641	U	G
6-Jul	0506	0516	F	I	12-Jul	1724	1735	U	G
6-Jul	1043	1058	U	I	12-Jul	1840	1851	U	I
6-Jul	1157	1212	U	I	12-Jul	2044	2054	U	I
6-Jul	1320	1335	U	I	13-Jul	0149	0159	U	I
6-Jul	1536	1548	U	I	13-Jul	0445	0457	U	I
6-Jul	1711	1723	F	I	13-Jul	0711	0723	U	I
6-Jul	1932	1941	U	I	13-Jul	1156	1207	U	I
6-Jul	2140	2149	U	I	13-Jul	1650	1707	F	I
6-Jul	2324	2334	U	I	13-Jul	1917	1931	F	I
7-Jul	0521	0531	U	I	13-Jul	2035	2045	U	I
7-Jul	0816	0827	U	I	14-Jul	0831	0843	U	I
7-Jul	0914	0930	F	I	14-Jul	1051	1102	U	I
7-Jul	1044	1105	F	I	14-Jul	1241	1252	U	I
7-Jul	1256	1319	F	I	14-Jul	1619	1630	U	I
7-Jul	1505	1525	F	I	14-Jul	2116	2126	U	I
7-Jul	1721	1732	U	I	15-Jul	0213	0223	U	I

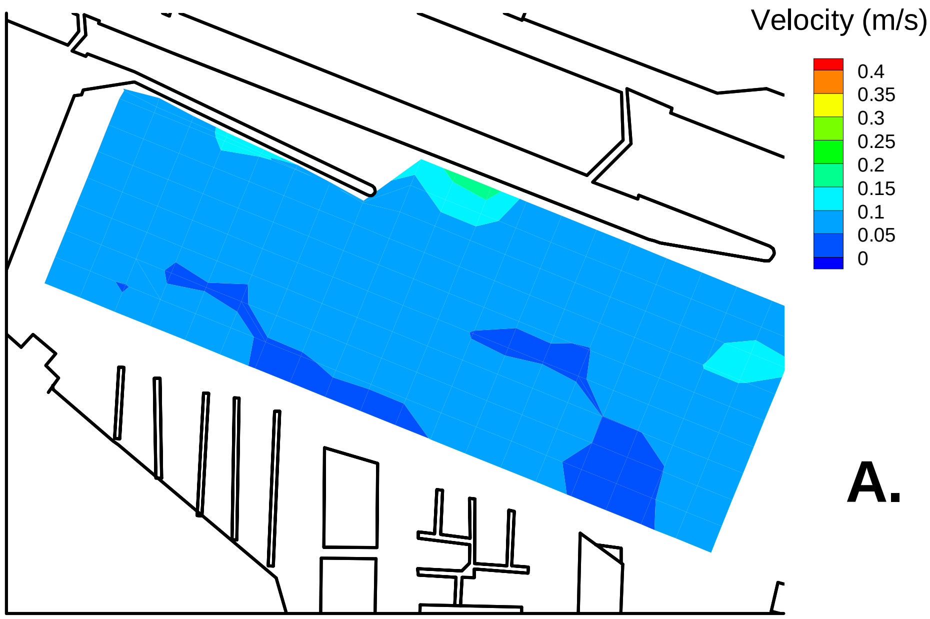
Appendix A. (cont.).

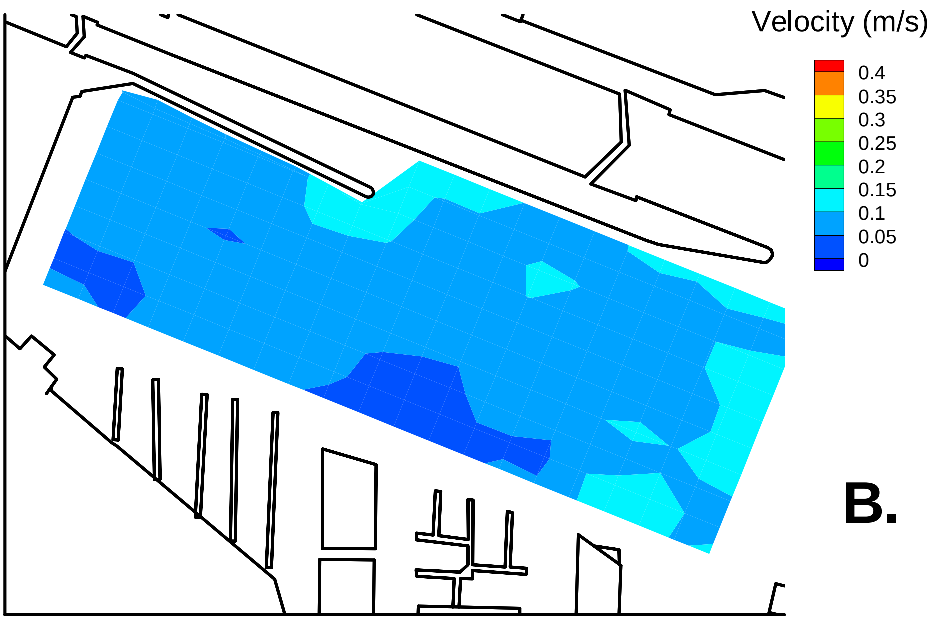
Date	Start Time	End Time	Chamber	Fill Type	Date	Start Time	End Time	Chamber	Fill Type
15-Jul	0820	0833	U	I	21-Jul	2055	2104	U	I
15-Jul	1050	1101	U	I	22-Jul	0138	0149	U	I
15-Jul	1215	1226	U	I	22-Jul	1051	1105	U	I
15-Jul	1321	1331	U	I	22-Jul	1216	1241	F	I
15-Jul	1435	1445	U	I	22-Jul	1520	1543	F	I
15-Jul	1624	1635	U	I	22-Jul	2039	2047	U	I
15-Jul	1834	1848	F	I	23-Jul	0211	0222	U	I
16-Jul	0747	0801	U	I	23-Jul	0251	0302	U	I
16-Jul	0929	0942	U	I	23-Jul	1025	1042	F	I
16-Jul	1056	1108	U	I	23-Jul	1417	1438	F	I
16-Jul	1439	1449	U	I	23-Jul	1624	1642	F	I
16-Jul	1628	1638	U	I	23-Jul	1951	2000	U	I
16-Jul	1753	1803	U	I	24-Jul	0058	0109	U	I
16-Jul	2055	2106	U	I	24-Jul	1002	1012	U	I
16-Jul	2313	2324	F	I	24-Jul	1105	1117	U	I
17-Jul	0634	0647	U	I	24-Jul	1245	1259	U	I
17-Jul	0718	0732	U	I	24-Jul	1408	1423	U	I
17-Jul	1218	1230	U	I	24-Jul	1522	1537	U	I
17-Jul	1343	1354	U	I	24-Jul	1744	1755	U	I
17-Jul	1636	1645	U	I	24-Jul	1839	1851	F	I
17-Jul	1814	1824	U	I	24-Jul	2029	2037	U	I
18-Jul	1143	1203	F	I	25-Jul	0604	0615	U	I
18-Jul	1301	1313	U	I	25-Jul	0753	0803	U	I
18-Jul	1412	1423	U	I	25-Jul	1015	1025	U	I
18-Jul	1658	1707	U	I	25-Jul	1108	1119	U	I
18-Jul	2007	2017	U	I	25-Jul	1233	1245	U	I
19-Jul	0355	0405	F	I	25-Jul	1337	1350	U	I
19-Jul	1102	1117	U	I	25-Jul	1456	1510	U	I
19-Jul	1221	1242	F	I	25-Jul	1633	1653	F	I
19-Jul	1352	1404	U	I	25-Jul	1917	1927	U	I
19-Jul	1523	1533	U	I	26-Jul	0030	0040	U	I
19-Jul	1623	1632	U	I	26-Jul	0331	0344	U	I
19-Jul	1737	1746	U	I	26-Jul	0925	0935	U	I
19-Jul	1809	1818	U	I	26-Jul	1139	1150	U	I
19-Jul	1847	1856	U	I	26-Jul	1343	1355	U	I
19-Jul	1949	1958	U	I	26-Jul	1453	1511	F	I
19-Jul	2030	2040	U	I	26-Jul	2110	2119	U	I
20-Jul	0005	0015	U	I	26-Jul	2215	2223	U	I
20-Jul	0127	0137	U	I	27-Jul	0254	0305	U	I
20-Jul	0840	0853	U	I	27-Jul	0409	0422	U	I
20-Jul	1123	1139	U	I	27-Jul	0916	0930	F	I
20-Jul	1315	1329	U	I	27-Jul	1157	1207	U	I
20-Jul	1508	1519	U	I	27-Jul	1357	1408	U	I
20-Jul	1713	1722	F	I	27-Jul	1450	1501	U	I
20-Jul	2046	2055	U	I	27-Jul	1549	1601	U	I
20-Jul	2210	2220	U	I	27-Jul	1640	1652	U	I
21-Jul	0623	0632	U	I	27-Jul	1730	1742	U	I
21-Jul	1106	1122	U	I	27-Jul	1814	1826	U	I
21-Jul	1229	1245	U	I	27-Jul	1953	2004	U	I
21-Jul	1808	1817	U	I	27-Jul	2205	2214	U	I

Appendix A. (cont.).

Date	Start Time	End Time	Chamber	Fill Type	Date	Start Time	End Time	Chamber	Fill Type
27-Jul	2350	2359	U	I	2-Aug	1423	1434	U	I
28-Jul	0039	0048	U	I	2-Aug	1609	1618	U	I
28-Jul	0153	0203	U	I	2-Aug	1817	1826	U	I
28-Jul	0329	0345	F	I	2-Aug	1930	1939	U	I
28-Jul	1044	1057	F	I	3-Aug	0632	0642	U	I
28-Jul	1203	1213	U	I	3-Aug	0857	0910	U	I
28-Jul	1255	1305	U	I	3-Aug	1137	1152	U	I
28-Jul	1448	1458	U	I	3-Aug	1302		U	I
29-Jul	0121	0130	U	I	3-Aug	1428	1440	U	I
29-Jul	0913	0932	F	I	3-Aug	1618	1628	F	I
29-Jul	1130	1141	U	I	3-Aug	1815	1823	F	I
29-Jul	1351	1401	U	I	3-Aug	2240	2250	U	I
29-Jul	1600	1610	U	I	4-Aug	0118	0129	U	I
29-Jul	1938	1949	U	I	4-Aug	0243	0254	F	I
29-Jul	2044	2057	F	I	4-Aug	0956	1016	F	I
30-Jul	0710	0724	U	I	4-Aug	1344	1357	U	I
30-Jul	1012	1025	U	I	4-Aug	1425		U	I
30-Jul	1106	1118	U	I	4-Aug	1706	1716	F	I
30-Jul	1203	1214	U	I	4-Aug	1835	1844	U	I
30-Jul	1301	1312	U	I	4-Aug	2000	2009	U	I
30-Jul	1603	1612	U	I	4-Aug	2125	2134	U	I
30-Jul	1828	1838	U	I	5-Aug	0550	0559	U	I
30-Jul	2023	2034	U	I	5-Aug	0722	0732	U	I
31-Jul	0121	0130	U	I	5-Aug	0833	0844	U	I
31-Jul	0239	0248	U	I	5-Aug	0954	1007	U	I
31-Jul	0551	0603	U	I	5-Aug	1224	1239	U	I
31-Jul	0709	0722	U	I	5-Aug	1407	1421	U	I
31-Jul	1057		U	I	5-Aug	1641	1653	F	I
31-Jul	1252	1303	U	I	5-Aug	1846	1854	F	I
31-Jul	1430	1441	F	I	5-Aug	2011	2020	U	I
31-Jul	1845	1857	F	I	5-Aug	2134	2143	U	I
31-Jul	2014	2024	U	I	6-Aug	0512	0522	U	I
1-Aug	0003	0013	U	I	6-Aug	0635	0645	U	I
1-Aug	0233	0242	U	I	6-Aug	1050	1103	U	I
1-Aug	0337	0347	F	I	6-Aug	1210	1232	F	I
1-Aug	0421	0432	F	I	6-Aug	1448	1501	U	I
1-Aug	0843	0857	U	I	6-Aug	1650	1701	U	I
1-Aug	1034	1048	U	I	6-Aug	1936	1945	F	I
1-Aug	1257	1314	F	I	7-Aug	0059	0110	U	I
1-Aug	1423	1436	F	I	7-Aug	0902	0912	U	I
1-Aug	1734	1743	U	I	7-Aug	0934	0945	U	I
1-Aug	1856	1905	F	I	7-Aug	1050	1102	U	I
2-Aug	0021	0034	F	I	7-Aug	1641	1653	U	I
2-Aug	0826	0839	U	I	7-Aug	1759	1811	F	I
2-Aug	1057	1112	U	I	7-Aug	1840	1850	U	I
2-Aug	1308	1321	U	I	7-Aug	2215	2224	U	I

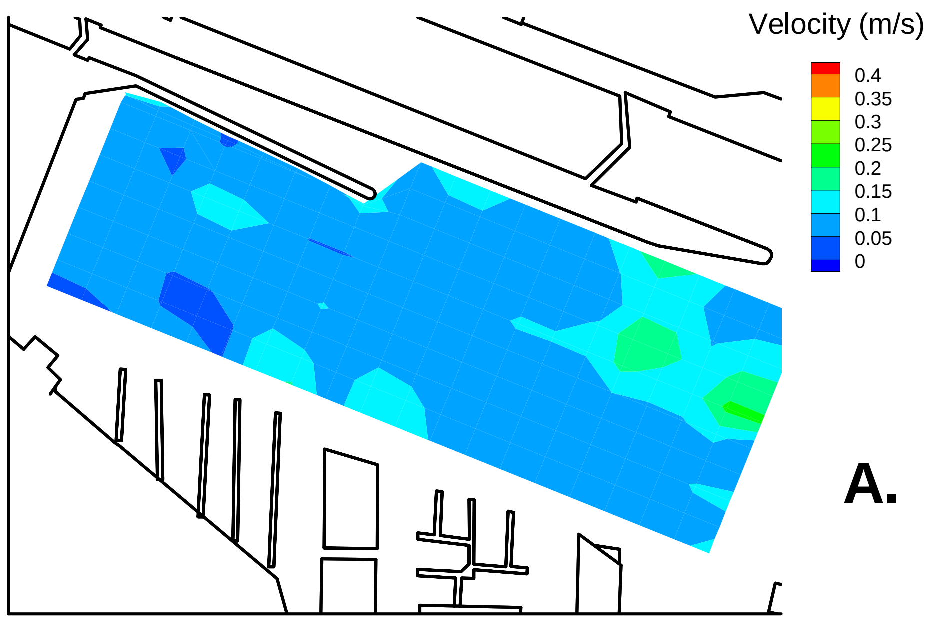
Appendix B. Current velocity patterns in the spillway forebay (treatments indicated in caption below plots).

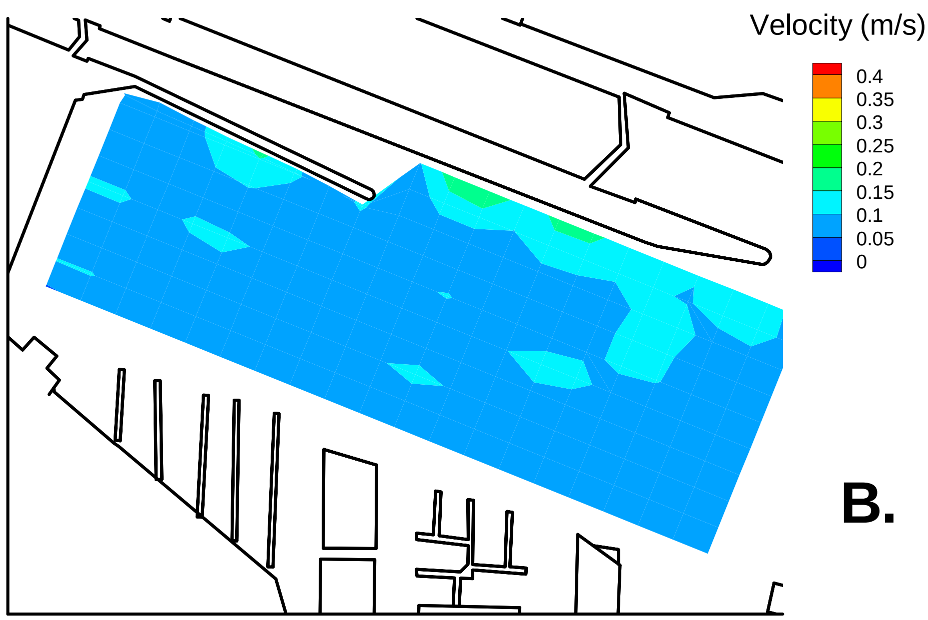




A.) Two hours after opening flumes 4A, 5B, and 5C; saltwater return closed.
B.) Three hours after opening flumes 4A, 5B, and 5C; saltwater return closed.

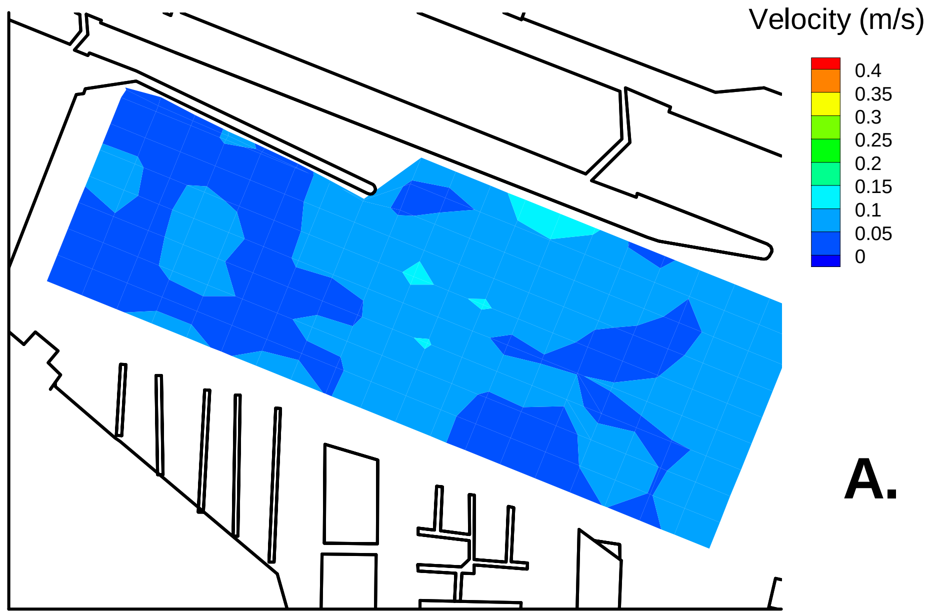
Appendix B. (Cont.).

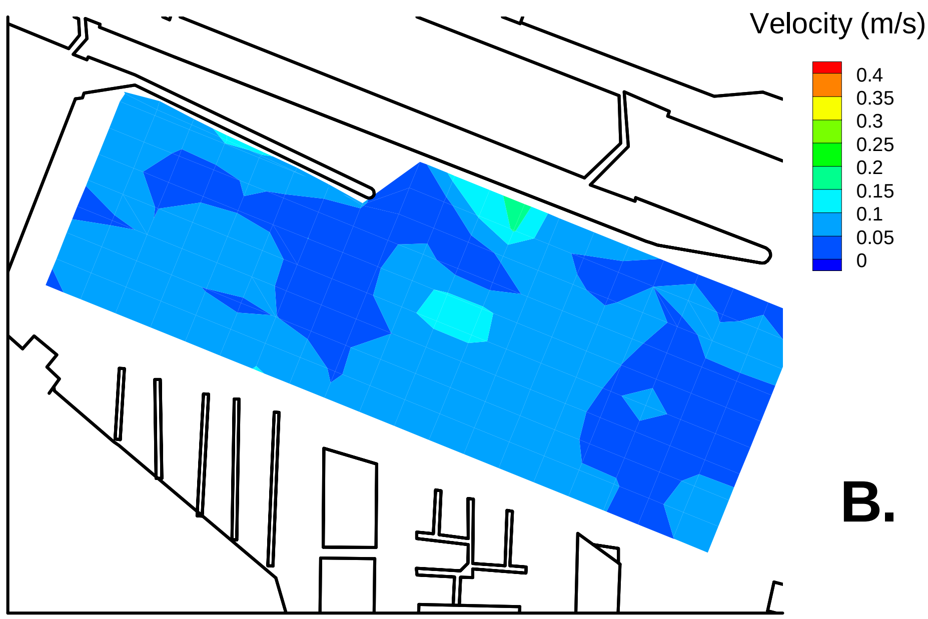




A.) Four hours after opening flumes 4A, 5B, and 5C; saltwater return closed.
B.) Five hours after opening flumes 4A, 5B, and 5C; saltwater return open.

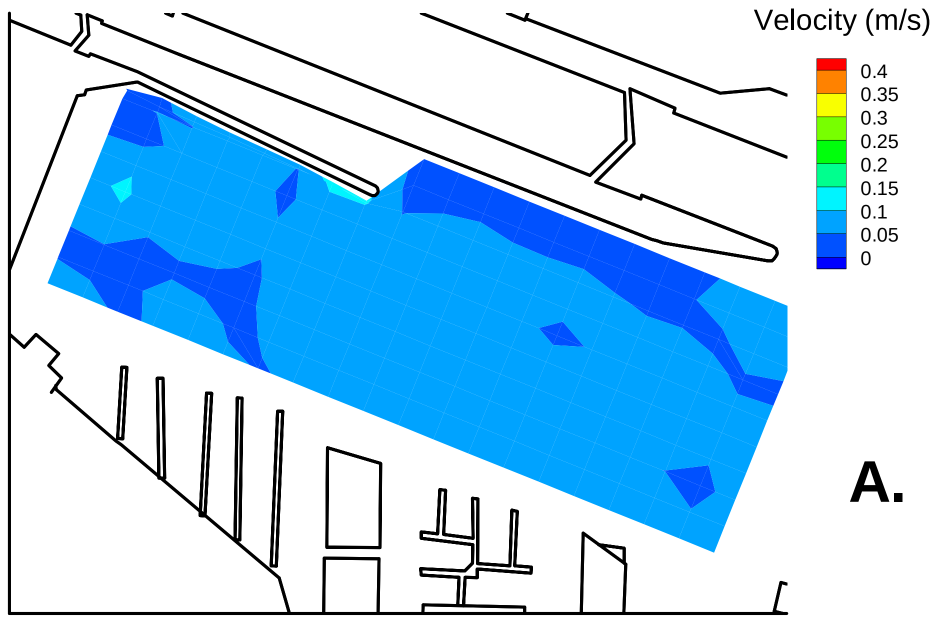
Appendix B. (Cont.).



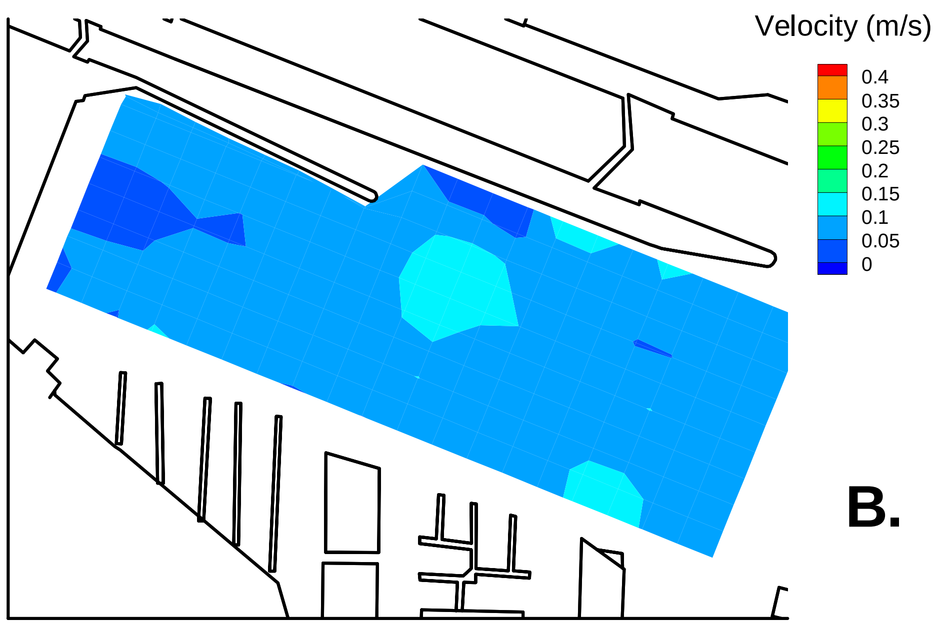


A.) Two hours after opening Flume 5B; saltwater return closed.
B.) Three hours after opening Flume 5B; saltwater return closed.

Appendix B. (Cont.).



A.



B.

A.) Four hours after opening Flume 5B; saltwater return closed.
B.) Five hours after opening Flume 5B; saltwater return open.